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THE AMERICAN SALT-DOME PROBLEMS IN THE LIGHT OF THE ROUMANIAN AND GERMAN SALT DOMES

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ABSTRACT

The American salt-dome problems are divisible into two parallel series, the one comprising problems of description, the other problems of theory. The solution of the latter are of necessity dependent upon solution of the former. The American salt domes consist of subcircular stocklike masses of salt, capped in most cases by limestone and gypsum-anhydrite, intruded into and surrounded by Pleistocene-Eocene or Eocene-Cretaceous sediments which dip quaquaversally away from the salt core. The domes show certain tendencies to alignment. They occur in regions of geologic quiescence where there has been no compressive folding.

The Roumanian salt domes are divisible into two groups, the Carpathian-Sub-Carpathian, and the Transylvanian. The Carpathian-Sub-Carpathian domes consist of narrow, elongated, vertical intrusions of the Salifere salt, clays, and marls along anticlinal axes and into a thick series of Pliocene and Miocene sediments. The domes occur on the edge of, and immediately in front of, the Carpathian sheet overthrust and are aligned along structural, mostly anticlinal, axes which reflect the effect of the Carpathian tectonics. If the difference in the structural setting is allowed for, the Roumanian domes closely resemble those in America. Their origin has usually been attributed to some phase of the tangential thrust of the Carpathian mountain-building forces. Krejci recently has raised strong objection to that theory, and has advanced a tectonico-isostatic theory according to which tectonic thrust is responsible for the localization and initiation of their formation, but the weight of the overlying sediments is responsible for the upthrust of the Salifere core. The Transylvanian domes occur in the Plio-Miocene Transylvanian basin. Although only poorly known, they seem to be very similar in form to the American domes. They are aligned on anticlinal axes which are subparallel to the periphery of the basin.

The German salt domes are a phase of the German salt deposits, which are a definitely sedimentary series with a well-defined, persistent, and characteristic section. One of the middle members carries marine fossils, and two members are potash bearing. On account of the extensive mining and exploration for this potash, and on account of the recognizable section in the salt series, the structural deformation of the salt deposits has been worked out in great detail. On the basis of form and structure of the salt deposits there is a complete gradation in type and in space from undeformed sedimentary beds through broad anticlines with slightly swollen cores of salt (Strassfurt type), sharp anticlines where the salt core is starting to pierce the cover (Asse type), to broken

anticlines in which the salt core has been squeezed up between the two flanks (Leine type), or to salt stocks (Hannoverian type) in which a pluglike mass of salt has been intruded for thousands of meters vertically into the overlying sediments. There seemingly can be no dispute that the German salt domes and salt ridges are the result of the plastic deformation and flow of a sedimentary salt series. The salt domes and ridges are aligned along Rhenish and Hercynian anticlinal axes. Many of the domes seem to be at the intersection of axes. The upthrust of the salt cores is attributed to tectonic thrust by Stille, who presents substantial evidence for such a theory. Lachman, Arrhenius, Seidl, and others argue less conclusively for an isostatic upthrust.

In view of the evidence of the Roumanian and German salt domes, in addition to what is known about the American domes, it would seem unreasonable to believe that the American salt domes are not the result of the plastic deformation and upthrust of a sedimentary salt series.

INTRODUCTION

The purpose of this paper is briefly to review the more salient features of the present-day knowledge of the German and the Roumanian salt domes, in order to point out the lessons which that knowledge may offer in regard to the problems of our American salt domes. This paper follows the line of earlier papers by Rogers and Van der Gracht. Since the time of those papers there has been a very great addition to literature available in regard to the German salt domes. The data on the German, Roumanian, and Transylvanian domes were obtained from a brief visit to the German and Roumanian domes, from oral discussions with Stille, Mrazec, Böckh, and Papp, and from papers listed in the bibliography at the end of this paper. A list of the published sheets of the *German Geological Survey*, on which salt domes occur, is also appended.

THE AMERICAN SALT DOMES

The American salt domes consist of pluglike masses of very pure rock salt, capped in most cases by limestone, gypsum, and anhydrite. These plugs occur in and cut through the unconsolidated sands and clays of the Pleistocene, Pliocene, Miocene, Oligocene, and Eocene in one case, and Eocene and Cretaceous in the other, and they are surrounded by beds dipping quaquaversally away from the salt core.

The salt core is very nearly circular in plan, has a relatively flat top, and very steeply sloping sides. In general, it tends to conform in profile to one of the three types shown in Figure 1. In only a very few cases does the salt overhang at all, and in those cases only slightly. The salt cores range in diameter from $\frac{1}{2}$ mile to 2 miles

(1 to $3\frac{1}{2}$ km.), and the depth to the top of the salt ranges from 15 feet to more than 2,000 feet (3 to 600+m.). The salt is known from three mines and various cores from wells. It is uniformly clear and granular, colorless, and very pure NaCl, except in faintly dark bands which are reported to contain scattered small crystals of anhydrite. Potash is known only in a single core from a depth of 4,800 feet in the Rycade Oil Corporation Gray No. 1 at Markham. The potash is present chiefly as sylvite. The salt of this core also contains algae.

The cap rock consists of a disklike mass of rock resting on the salt table, in a few cases extending slightly down the flanks of the salt core, and possibly in a few cases wedging out into the flank sedi-

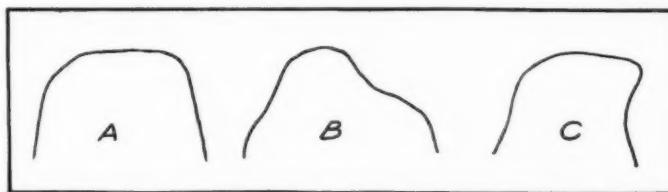


FIG. 1.—Three main types of profiles of American salt domes. *A* = Pine Prairie, *B* = New Iberia, *C* = Vinton.

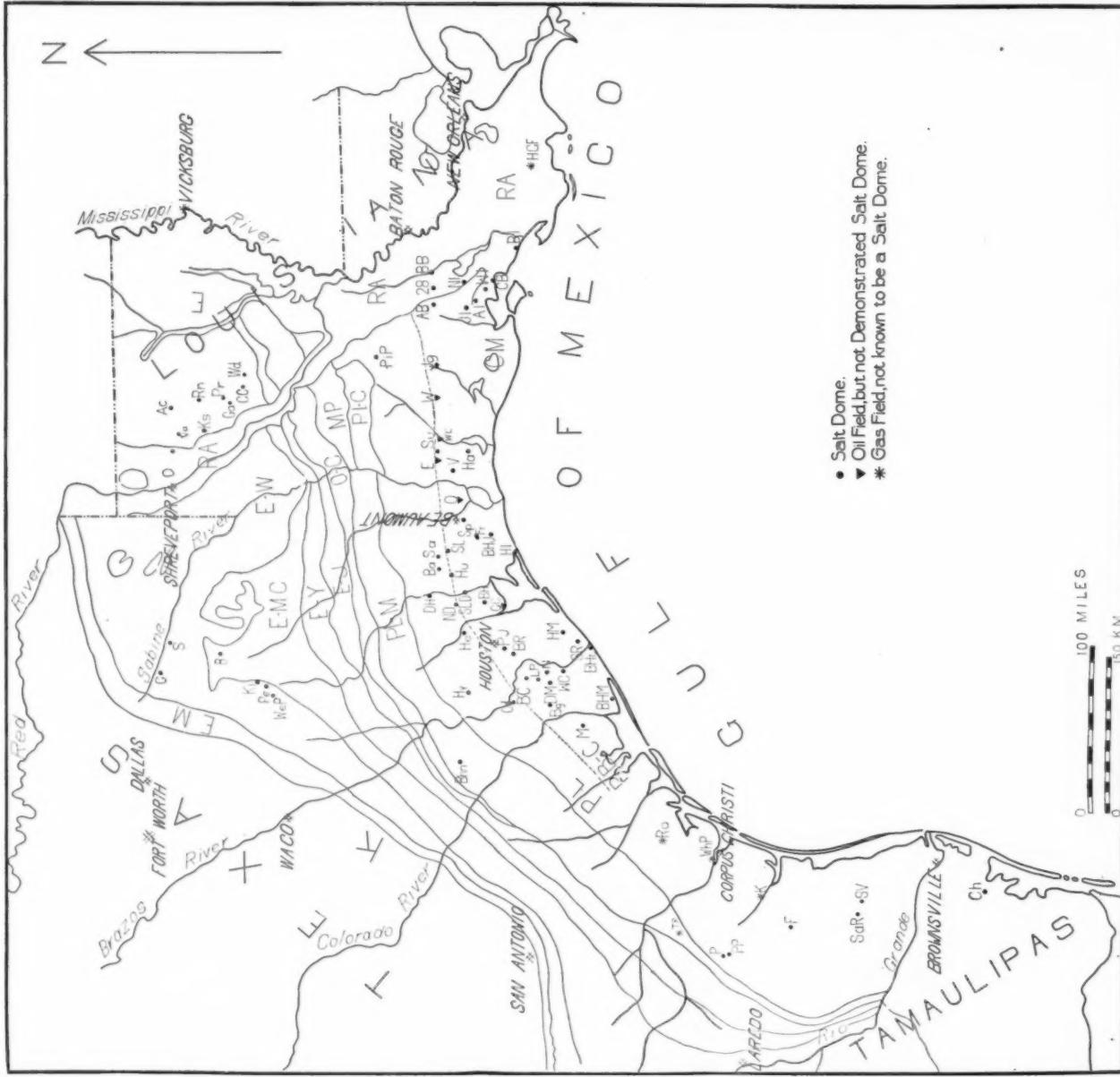
ments. The cap rock in most cases consists of uniform, even-grained, rather homogeneous anhydrite or of well-crystallized selenite with cleavage faces some centimeters or even decimeters in diameter. The gypsum has apparently resulted from the alteration of the anhydrite. The cap in many cases is partly composed of limestone or dolomitic limestone. The limestone tends to cap the anhydrite-gypsum cap, but in some cases is reported to be found within the main body of the anhydrite-gypsum mass. Some of the Louisiana domes have a thick cap composed chiefly of limestone. The cap ranges in thickness up to 1,000 feet (300 m.). Many of the domes, as, for example, many of those in central southern Louisiana, have no cap rock at all; the Sulphur, Louisiana, dome, at the other extreme, has a cap slightly over 1,000 feet thick. The cap rock averages, on the whole, around 300 to 400 feet (100 m.) in thickness. Native sulphur is found to some extent as a secondary constituent of the

cap rock of many domes and, in a few cases, in very considerable quantities.

The American salt domes are found in every case to cut across unconsolidated, or only slightly consolidated, sedimentary formations. They occur in three groups: a coastal group, all of which lie within 150 miles (250 km.) of the coast, a group in northern Louisiana, and a group in central east Texas. The coastal group of domes occurs in a region where the unconsolidated sands and clays of the Tertiary are over 6,000 feet (2,000 m.) thick, and these domes are known to cut formations of all periods from the Claiborne (Eocene) to Recent. Beds earlier than Claiborne in age have not been identified as yet in the wells on and around these domes. The two interior groups of domes occur in regions of Upper Cretaceous and of Eocene formations, and the salt domes cut Cretaceous and Eocene formations.

All the American salt domes occur in regions of geologic quiescence, where the beds have not been subjected to lateral folding movements and show only regional dip or gentle warping. Around the salt domes, however, there is marked deformation of the beds. At many of the interior domes, such as West Point and Keechi, the beds exposed at the surface can be seen dipping steeply away from the center of the dome, and beds whose normal stratigraphic level is several thousand feet below the surface have been brought to the surface. Wherever it has been possible to draw subsurface cross-sections across the coastal domes, the same marked dips away from the salt core have been revealed. On the deeper beds at Damon Mound the dip amounts to around 45 degrees, even out as far as half a mile from the edge of the salt. The dips around many dome seem to be much gentler than at Damon Mound. The upper beds may extend clear across above the top of the salt, and in that case show only gentle warping. With increasing depth, the dip of the beds becomes increasingly greater. According to the subsurface work of the geologists of the Shreveport office of the Amerada Petroleum Corporation, the presence of salt domes with marked uplift of surrounding beds is not shown in the regional-structure contour maps of northern Louisiana.

The areal arrangement of the Gulf salt domes is shown in Plate



SKETCH GEOLOGIC MAP OF TEXAS AND LOUISIANA SHOWING THE LOCATION OF THE SALT DOMES AND NON-SALT DOME GULF COAST OIL FIELDS

Geology largely after Deussen, Dumble, Harris, and Marion. *R*-*A* = river alluvium, *P*-*BC* = Beaumont clay (Pliocene), *P*-*C* = Citronelle (Pliocene), *P*-*M* = Plio-Miocene, *M*-*P* = Pascagoula (Miocene), *O*-*C* = Corrigan or Catahoula (Oligocene), *E*-*J* = Jackson (Eocene), *V* = Vega, *E*-*MC* = Cook Mt.-Mt. Selman, *E*-*M* = Midway (Eocene), *M* = Cretaceous.

KEY TO SALT DOMES AND OIL AND GAS FIELDS

AB	Anse la Butte	Ch	Chapado	Ki	Kiechi	Sa	Saratoga
AC	Arcadia	DH	Davis Hill	Kl	Kings	SL	Sour Lake
AI	Avery Island	DM	Damon Mound	LP	Long Point	SLD	South Liberty Dayton
AM	Ames	ED	Edgerly	MR	Markham	SP	Spindletop
AR	Aransas	FM	Fannier	NA	Nash	SR	Stratton Ridge
BC	Bayou Bolliou	FL	Fannet	ND	North Dayton	SW	Sulphur
BH	Big Creek	GA	Grand Saline	NI	New Iberia	SV	Salt Vieja
BM	Barbers Hill	GC	Goldonna	O	Orange	V	Vinton
BR	Big Hill Jefferson	HC	Goose Creek	OB	Orchard	WC	Welsh
CH	Big Hill Matagorda	HA	Huckleberry	PA	Palangana	WC	West Columbia
CO	Brenham	HE	Humble	PE	Pleistocene	WD	Winnfield
DM	Bryan Heights	HGP	Houma Gas Field	PP	Pine Prairie	WP	Whites Point
E	Belle Isle	HM	Houma Mound	PJ	Pierce Junction	WL	Weeks Island
EM	Blue Ridge	HU	Huskins Mound	PC	Pieces	WL	West Lake
EP	Bisteneau	HV	Hull	PP	Piedras Pinas	Ro	Refugio gas well
F	Cote Blanche	HY	Hockley	R	Rayburn	S	Stearns Saline
G	Cedar Creek	J	Jefferson Island	28	Section 28	K	Kieberg (Kingsville) Gas Field

26. The interior Texas domes lie either on an elliptic arc or on a faintly curved line parallel to the Balcones fault and on a crossline. The interior Louisiana domes do not fall distinctly on any lines. Of the coastal group of domes, those in southeast Texas show a general tendency to fall on lines trending NNE.-SSW. and bending slightly SW. toward their southern extremities. There is also a suggestion of NW.-SE. crosslines, but very possibly the alignment of the domes along these lines is entirely accidental. The five domes in south Texas lie on a NNW.-SSE. line. In southern Louisiana the alignment is much more obvious; the Five Islands form a well-marked line, convex toward the southwest, and striking NW.-SE.; Anse la Butte and New Iberia are on a parallel line; there is also the well-marked E.-W. line on which fall five salt domes and two oil fields not known to be salt domes.

The problems of the American salt domes, as the writer sees them, are listed in Table I. Although seemingly somewhat exhaustive, the list is far from complete. Detailed attention to an analysis of each of the problems will in most cases reveal a very considerable number of subordinate problems or phases of the main problem which have not been listed. A dual division of the problems has been made into what can be called (*a*) problems of description and (*b*) problems of theory. The "problems of description" deal essentially with questions of fact in regard to the actual physical makeup of the American salt domes—questions which can be solved by observation and description. The "problems of theory" deal with the questions of interpretation of these facts to the end that we may explain the method of formation of such actual physical structures as we find the American salt domes to be.

The problems of theory are of necessity dependent upon the solution of the respective problems of description. Series of alternative hypotheses can be advanced *a priori*, but the probability of the various theories can be evaluated only with the solution of the problems of description. A very large part of the discussions by American geologists of those problems of theory is invalidated because of the fact that the discussions were based on inadequate solution of those problems of description, or upon an inadequate grasp of what was known in regard to the solution of those problems.

TABLE I

OUTLINE OF AMERICAN SALT-DOME PROBLEMS

Problems of Description	Problems of Theory
A. Physiography	
I. Descriptive classification of salt-dome mounds	I. Cause of the deformation resulting in the formation of salt-dome mounds
II. Relation of surface to subsurface	a) of simple, convex mounds
III. Relation of mounds to physiography of surrounding region	b) Of secondary and subsidiary mounds
B. Structure of salt dome—descriptive classification of salt domes in regard to:	c) Of central depressions
I. Salt core	II. Age of the salt-dome mounds
a) Form of salt mass	I. Source of the salt
(1) Top	II. Method of <i>mise-en-place</i>
(2) Flanks	III. Mechanics of <i>mise-en-place</i>
(3) Bottom	IV. Age of the salt
b) Composition and petrography of salt mass	
c) Structure of salt mass	
II. Cap	I. Origin of the cap
a) Composition of the cap	a) Anhydrite-gypsum
b) Petrography of the cap	(1) Source of the anhydrite-gypsum
c) Paragenetic relations of the different members of the cap	(2) Reactions and conditions resulting in deposition of $\text{CaSO}_4 \pm 2 \text{H}_2\text{O}$ or in alteration of limestone to $\text{CaSO}_4 \pm 2 \text{H}_2\text{O}$, if the anhydrite-gypsum is secondary
d) Form of cap	b) Limestone
(1) Position and relation to salt core	(1) Source of the limestone
(2) Position and relation to super-salt-sediments	(2) Reaction and conditions resulting in its deposition, if it is secondary
(3) Position and relation to flank beds	
e) Structure of cap	c) Sulphur
	(1) Source of sulphur
	(2) Reactions resulting in its deposition
III. Surrounding sediments	II. Age of the cap (especially in reference to age of salt and of salt dome)
a) Supersalt beds	
(1) Structure	
(2) Petrography	

TABLE I—*Continued*

Problems of Description	Problems of Theory
(3) Stratigraphy	III. Relation, if any, of the cap to the Oligocene limestone
(4) Age	I. Cause of thinning of section and of thinning of some beds above the salt
b) Flank beds	II. Historical geology of salt domes
(1) Stratigraphic section	a) At the beginning of upthrust
(a) Normal section away from salt domes	b) Periods of maximum movements vs. periods of relative quiescence
(b) Section near dome	c) End of the movement
(2) Structure of flanks	d) Amount of upthrust that took place in each period
(a) General	III. Reason for predominance (?) of sand near salt core
(b) Faults	IV. Reason for calcareous (?) cementation of sands near salt core
(c) Unconformities	V. Cause of any such variation (if any) in ratio sand to clay
(d) Relation of flank beds to salt core	VI. Cause of any such variation (if any) in SO_4 , Cl , CaCO_3 , and sulphides
(3) Petrography	
(a) Near the salt	
(b) Out from the salt	
c) Surface	
(1) Variation of ratio sand to clay on and off salt dome	I. Regional forces and conditions which result in salt-dome activity
(2) Variation in SO_4 , Cl , CaCO_3 , and sulphides in soils on and off salt domes	II. Localization of salt domes
C. Regional relations of the salt domes	
I. Tectonic-orographic framework of the general region in which the salt domes occur	
II. Alignment of the salt domes	
III. Relation of salt-dome lines to the tectonic-orographic frame in which they occur	
IV. Relation type of dome to position, in the tectonic-orographic frame and to thickness and character of setting	

TABLE I—Continued

Problems of Description	Problems of Theory
D. Salt-dome waters	I. Cause of any variation
I. Composition and concentration in reference to depth and stratigraphic horizon, for normal Gulf Coast waters	a) Source of materials in solution
II. Variation of salt-dome waters	b) Reactions
a) With proximity to dome	I. Source of the materials
b) With depth	II. Reactions resulting in the formation of the minerals
c) In cap	I. Cause of high temperature and gradient in cap rock
E. Mineralogy of the salt domes	II. Cause of low gradient in flank
F. Salt-dome geothermal temperatures and gradients	III. Cause of areal variation of gradient
I. Variation with depth	IV. Cause of high temperature (if so) of water than of oil
II. Variation in relation to oil-and-water relations	
III. Variation with proximity to dome	
IV. Areal variation around dome	
V. Variation with regard to age of oil field	
G. Petroleum and natural gas	
I. Descriptive classification of kinds of oil on Gulf Coast	I. Source of sources of the oil
II. Composition of various oils	II. <i>Mise-en-place</i> of the oil
III. Modes of occurrence	III. Reason for extreme differentiation of the oil on some domes
IV. Regional occurrence of oil	IV. Age of oil and of oil deposits
V. Regional occurrence of natural gas	V. Why are some domes productive, others barren?
VI. Stratigraphic relations of natural gas	
VII. Stratigraphic relations of oil	
VIII. Variation of character and gravity with depth, stratigraphic horizon, and dome	
IX. Oil-production figures	
a) Total production per dome	

TABLE I—Continued

Problems of Description	Problems of Theory
b) Per acreage production per dome	I. Method by which volcanic activity could produce salt domes
c) Productivity in relation to horizon	II. Possible connection in time and space of salt-dome activity with volcanic activity
d) Productivity of individual wells	I. Method by which a salt deposit of the type of the salt domes could be formed from ascending brine solutions or by escaping gas
e) Productivity with different types of spacing	II. Why would not ascending solutions be diluted instead of concentrated?
H. Volcanic theory of origin of salt dome	III. Why would not deposit be in form of a stockwork of salt veins ramifying through sediments?
I. Evidences of volcanism in Gulf Coast	
II. Evidences of solfataric action in Gulf Coast	
III. Association of any such evidence of volcanism or solfataric action with salt domes of Gulf Coast	
I. Ascending brine or gas theories of the origin of salt domes	
I. Evidence of ascending brine solutions of any amount in salt-dome area	
a) Present brine springs	
b) Evidence of subsurface brine circulation of sufficient amount	
II. Evidence of amount of gas escaping from domes	
III. Evidence that faulting or anything else could imitate an upward current of water or gas in any considerable amount upward through many thousand feet of gumbos and sands	
IV. Evidence that any such movement of brine or gas could maintain itself	
V. Evidence (a) that growing salt crystals is of order to	

TABLE I—*Continued*

Problems of Description	Problems of Theory
account for doming; (b) evidence of such growth in character of salt crystals	
J. Tectonic theories	
I. Evidence of plasticity of rock salt sufficient to allow flowage	
II. Evidence of movement by recrystallization under pres- sure	
III. Force of lateral compression	I. Would not friction at sides of rising core counterbalance the possible lack of density?
a) Evidence of presence of lateral compression in general region	
b) Evidence of association of salt domes with such lateral compression	
c) Evidence in structure of salt dome of lateral com- pression	
IV. Isostatic forces	
a) Amount of compensation around salt domes	
b) Mass of salt core vs. mass of surrounding sedi- ments	
K. Geophysical relations of salt domes	
L. Economic importance of salt domes	I. Probable reserves of petroleum, sulphur, salt, potash, gypsum

The papers of the present symposium in large part deal with the problems of description, and offer a wealth of information in regard to the American salt domes. But when the broader outlines of this wealth have become evident, it will be seen that knowledge of our American salt domes is woefully scanty and inadequate. We have fairly detailed, but in no way complete, knowledge of the outer form of the upper part of the salt core, in the case of a very few domes, of the cap, and in the case of the rest, only scattered bits of knowledge. We have fair information in regard to the structural relations

of the sedimentary beds in the more recently discovered oil fields, and some knowledge concerning the structure of the upper beds in the interior groups of domes. But we have very scanty information in regard to the salt core, which, indeed, is the core of the problem. In the absence of adequate solution of the problems of description of the salt core, we shall be unable to come to any decision between the possible *a priori* solutions of the problems of theory. In virtue of the large potash mines, and of the extensive exploration for potash in Germany, the German geologists have been able to come to a far more adequate solution of the problems of description and theory than we have in the case of any of the problems concerning our American domes, and they also have been able to come to as adequate a solution of the problems of sedimentary structure as have we. The solution of the problems of description of the Roumanian domes has not gone as far on the whole as in the case of the American domes, but as conditions in the two areas are different, the fragmentary knowledge obtained from Roumanian sources helps to throw light on the solution of the problems of the American domes.

ROUMANIAN SALT DOMES

In Roumania salt domes occur (*a*) in the outer edge of the bow of the Carpathian Mountains and in the adjacent Sub-Carpathian zone, and (*b*) in the Transylvanian basin.

CARPATHIAN AND SUB-CARPATHIAN SALT DOMES

The broad features of the geology of the region in which the first group of salt domes occur are as follows: The Carpathian Mountain system, bending in a sweeping arc from Galicia southward into the center of Roumania and then westward, is composed of (*a*) an "island" of crystalline rocks at the northern end of the system, (*b*) an "island" of crystalline rocks composing the western third of the Roumanian Carpathians, and (*c*) the Flysch, Early Tertiary, zone (Fig. 2). The Carpathians are composed of folds, in many cases broken or overturned, and of gigantic overthrusts in which the active thrust has been outward.

From the Galician border southward, and then westward as far as the valley of Dambovitză River, the outer edge of the Carpathian

Mountain zone is bordered by the Sub-Carpathian Miocene zone. This zone is divisible into three subzones: (1) a northern Moldavian subzone, which is composed of open folds and separated by a fault

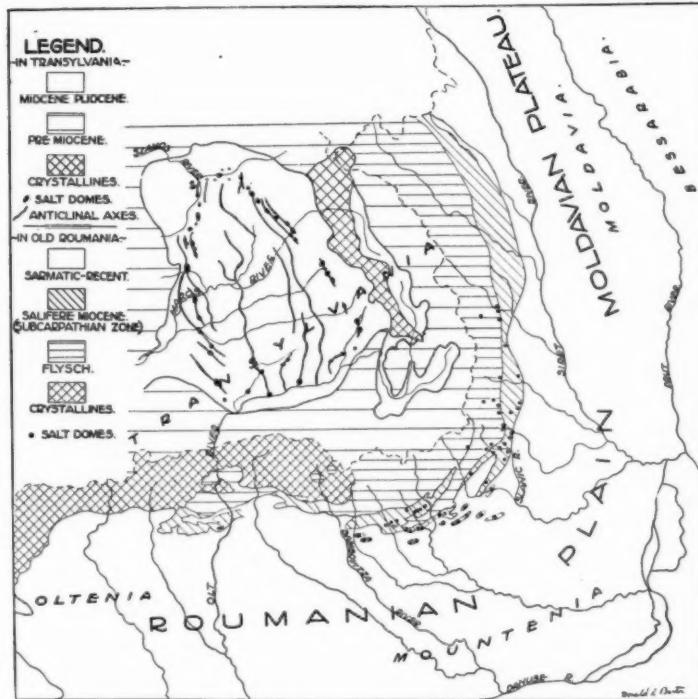


FIG. 2.—Geologic sketch map of Roumania showing the location of the Transylvanian, Carpathian, and Sub-Carpathian salt domes—after Mrazec, Papp, and Böckh.

from the Moldavian Plateau to the east; (2) a southern Moldavian zone extending as far south as the valley of Slanic River. This zone is characterized by crowded folds and is bordered by Sarmatic, Meotic, Pontic, and Levantinic, whose beds, thrown back at the contact with the Miocene, drop slowly to the Roumanian plain; and (3) the southern Carpathian subzone, extending from Slanic

River to Dambovitza River, and presenting a very complex structure. At the elbow of the Carpathian arc a bundle of folds diverge from the Carpathian curve and plunge to the southwest. The folds in the Miocene beds dip under Pliocene, which shows conformable but lesser folding, dying away to the southwest. An important structural feature of this zone is the Bay of Slanic, a tectonic bay of Miocene rocks extending back into the zone of the Flysch. This subzone is bordered by the Roumanian plain.

The salt domes of the first group are found indiscriminately in the second and third Sub-Carpathian zones, in the adjacent portion of the zone of the Flysch, and in addition, in two isolated domes west of Dambovitza River. In the second Sub-Carpathian subzone and the adjacent portion of the zone of the Flysch the salt domes are about equally distributed between the two zones and the distribution of the domes does not seem to show conformity in plan to the contact between the zones, unless possibly there is a tendency for domes of the zone of the Flysch to occur just within the outer margin of the zone. In the third Sub-Carpathian zone and adjacent portion of the zone of the Flysch the salt domes occur in the Sub-Carpathian zone but not in the zone of the Flysch. It is a notable fact that there are a great number of salt domes in the Miocene Bay of Slanic, and off the outer side of the Spur of Valeni, which is the Flysch tectonic peninsula inclosing the Bay of Slanic, but none on the spur itself. The number of the known salt domes in this first group of domes, according to Voistesti, is now well over seventy-five.

The salt domes are large, lenticular massifs of granular crystalline salt of a high degree of purity. The stratification of the salt is marked by alternating dark and light beds and by rare beds of argillaceous material, which in some cases contain the more-or-less carbonized débris of tree trunks. The salt, even including the "black" salt, has a NaCl content of 98.0-99.5 per cent.

The salt is merely part of the peculiar type of fold called by Mrazec "diapir" fold, or by Krejci "piercement" folds (*Durchspießungsfalten*) and "outbreaks" (*Aufbrüche*). The characteristic feature of a diapir fold, according to Mrazec's definition, is that the beds of the core tend to pierce the overlying beds of the arch, and although laid down conformably, the beds of the core dip more

steeply than the beds of the flank or roof. The piercement fold is the characteristic diapir fold in its earlier stages; the outbreak, in the later, extreme phase in which plastic, mobile sediments of the core have been intruded, mostly vertically, into the overlying sedi-

TABLE II
STRATIGRAPHIC SECTION IN THE SUB-CARPATHIAN ZONE (AFTER KREJCI)

Age		Lithologic Character	Type of Deposits
Quaternary		Alluvium	Fluviatile and terrestrial
Levantic		Cross-bedded sand and gravel and marl	Fluviatile and littoral
Dacic		Marls and sands	Littoral
Pliocene	Pontic	Upper	Sand
		Middle and Lower	Marl
	Meotic	Fresh-water Meotic	Sand and sandstone. Marl, sand, and calcareous sandstone, petrolierous
		Dosinia horizon	Marl and calcareous sandstone, petrolierous
Miocene	Sarmatic	Upper	Missing
		Middle	Limestone, calcareous sandstone, sand, and marl
		Lower	Marl and calcareous sandstone
	Salifere	Vindobonic	Marl, sandstone, dacite tuff
		Burdigalic	Sand, marl, and conglomerate
		Aquitanic	Clay, marl, gypsum, salt, and petroleum

ments. The core in both the piercement folds and the outbreaks is composed predominantly of the marls of the Salifere (see Table II) and subordinately of salt, gypsum, sand, and sandstone. The salt seems to form the backbone of the outbreaks and apparently is present in relatively greater amount in the small outbreaks which come from great depth than the broader, more gentle ones coming from lesser depths.

The exact form of the diapir folds in Roumania is not well described in the literature. It is said by Krejci to be that of an ethmolith. In plan it seems to be a flattened ellipse, in some cases slightly crescent-shaped, with the convex side indifferently to the north or south. The outline of the Baicoi dome is a flattened ellipse several kilometers long and slightly over half a kilometer wide. The Ocnele-Mari dome is slightly more than 3 kilometers long by $\frac{1}{2}$ kilometer wide. In cross-section the core rises vertically from depths of 2,000 meters with relatively little change in width, tends in outline to approximate a logarithmic spiral, and in its upper part is overturned, predominately to the south, but at Gura-Ocnitzei and Baicoi toward the west and south, at Moreni toward both north and south, and at Floresti toward the north. Cross-sections of the Baicoi and the Moreni domes are given in Figures 3 and 4. If an outbreak does not reach to the surface it may be reflected in the surface beds by a normal structural dome.

Cap rock similar to the cap rock of the American and the German salt domes is not present. A thick mantle of tectonic breccia is described by Voitesti as characterizing the domes in the zone of the Flysch. The breccia is composed of large or small angular and rounded pieces of limestone, sandstone, marl, shale, crystalline schist, and eruptive rocks, in a matrix of argillaceous material. The tectonic character of most of the breccias is severely questioned by Krejci, who interprets them as surface formations.

The source of the salt is most commonly held by Roumanian geologists to be salt forma-

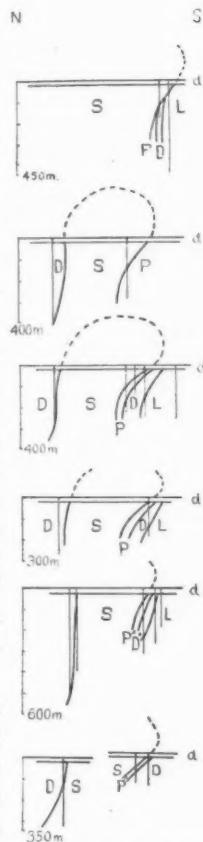


FIG. 3.—East-west series of north-south sections across the Baicoi dome. After Mrazec.

d = Diluvium,
 L = Levantic (gravels, sands, and shaly sands) (*landestii* bed)
 D = Dacian (*Vinpara bifasciata* beds) (sands and marls)
 P = Pontian (shaly marls and, in places, sand)
 S = Salifers Miocene, gray marls and sandstones over a main salt core

tions in the Eocene-Oligocene or in the Miocene. As the salt cores in the zone of the Flysch cut all formations of the Flysch geosyncline, and in the sub-Carpathian zone formations from Jurassic to Quaternary, Voistesti believes that the salt is definitely older than Triassic and has formulated the theory that it is a pre-Cambrian chemical precipitate. On account of the overthrusting, however, it is not safe to predicate that the salt is older than all formations it pierces.

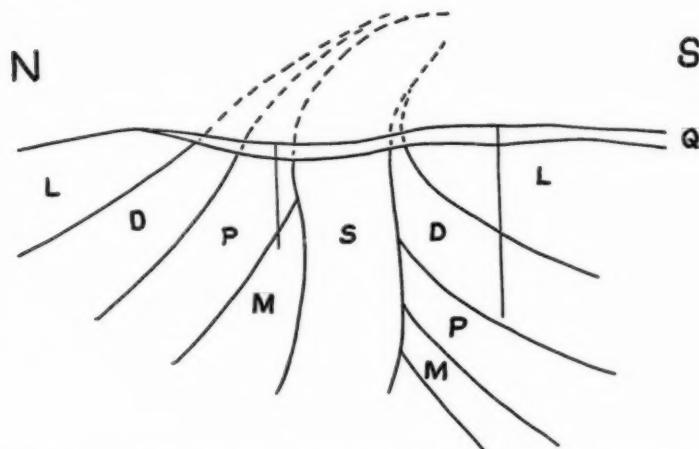


FIG. 4.—Section across the Moreni dome. After Voistesti. *Q*=Quaternary, *L*=Levantic, *D*=Dacic, *P*=Pontic, *M*=Meotic, *S*=Salifere.

On the flanks, the Meotic and Pontic either are present in narrow bands, steeply uplifted, or have been cut off in great depth against the thrust surface of the core, and the Dacic, or even the Levantic, lie directly against the Salifere. Commonly on the south flank the Meotic, Pontic, and Dacic, and in some cases the Levantic, are overturned toward the south.

The age of the uplift of the domes is Sarmatic to Levantic, according to Krejci. The uplift began in Sarmatic and Meotic times. Perhaps by Pontic, and at least by Dacic, times some of the outbreaks had been uplifted to such an extent that Dacic beds were deposited discordantly across their eroded crests. The main period

of uplift began in upper Dacic times, and the Levantic beds were laid down transgressively across the steeply dipping beds of the older formations. As the Levantic itself is steeply uplifted or overturned in places, the movement continued until after the end of Levantic times, but as the diluvial stream terraces do not seem to be warped where they cross the outbreaks, the movement seems to have died out before Pleistocene times.

There is a definite tendency toward an alignment of domes along structural lines parallel to the front of the Carpathian overthrust (Fig. 2), and these structural lines apparently tend to be anticlinal axes. A great many salt domes occur within the Bay of Slanic which, according to the older interpretation, is a geosyncline, but they are on anticlinal lines.

The theories of origin of the Roumanian domes are mainly two: (1) the tectonic theory of Mrazec, which seems to have had rather general acceptance among Roumanian geologists until recently; and (2) the tectonic-isostatic theory recently advanced by Krejci. According to Mrazec a diapir fold represents the first stage of an overthrust. The diagrams in Figure 5 show his conception of the process: (a) by depression of the foreland a flexure is formed in which, as the result of the thrust of the foreland, there begins underthrust of the downthrown block of competent bed, II, against the upthrown block, I; (b) as the underthrust progresses, the understratum, III, is caught between I and II, and is forced up and partially over II, forming a diapir fold; (c) if the underthrusting is continued still farther, the piercing core of the substratum caught between I and II will be torn from its roots and will exist as an uprooted core or *klippe*, such as is believed to occur at certain points along the line of Tintea-Baicoi-Moreni. The thrust in the case of the Roumanian domes is interpreted as a phase of the tangential thrust which has caused the overthrusting in the Carpathians. Since the American domes are in a region of great geologic tranquility, where there has been no horizontal compressive thrust since far back into the geologic past, it is not possible rationally to postulate for the origin of American domes any compressive thrust sufficient to cause folding or overthrusting, and the writer long has thought that the Roumanian geologists were emphasizing too

strongly genetic relationship between the origin of the Roumanian domes and the tectonic thrust from the Carpathian mountain-building forces.

Against the tectonic theory Krejci has raised the objections: (a) that although the mountain-building movements decreased from

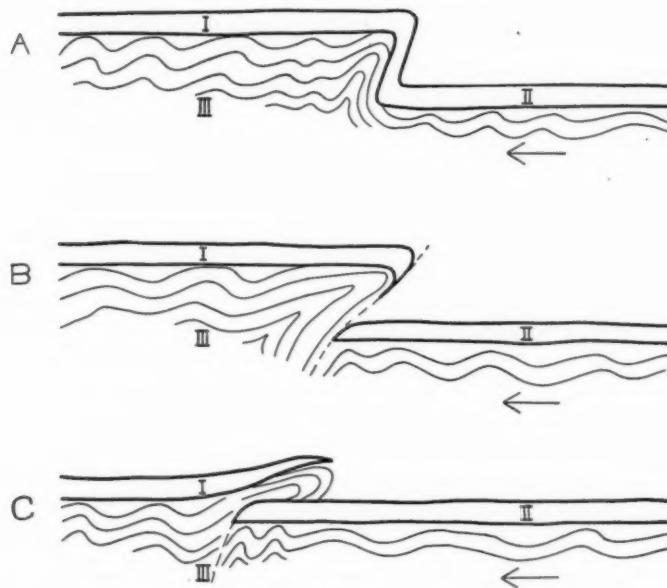


FIG. 5.—Diagrammatic explanation of the origin of diapir folds of the Sub-Carpathian type. After Mrazec.

Sarmatic times on and had died out by Levantic times, the formation of the outbreaks did not begin until Sarmatic and Meotic times, reached its maximum in Dacic times, and continued with almost undiminished force into Levantic times; and (b) that although the intensity of folding within the Carpathians along the border of the southern Sub-Carpathian zone increases from east to west, the intensity of formation of the diapir folds decreases from east to west. Krejci postulates as a fundamental regional requisite for the formation of the Roumanian salt domes the presence of a

formation composed of mobile plastic materials such as salt, clay, and marl, located at the front of an active sheet overthrust, and overlain by a competent cover which is neither too thick nor too thin and which transgresses at least to the edge of the overthrust sheet. He then conceives the formation of the outbreaks as taking place in three steps: (1) the formation of wavelike folds in the competent cover through the effects of thrust by the overthrust sheet; (2) the transformation of the folds into piercement folds through the yielding upward of the mobile plastic underlying formation under the effect of the same thrust, the upward movement being augmented at the points of least resistance along the crests of the folds; and (3) the transformation of the piercement folds into outbreaks through the extrusion of the plastic core vertically upward into the overlying sediments, the movement taking place isostatically under the effect of the pressure of the overlying sediments. Theoretically, the motive force in the final upthrust of the core could be tectonic thrust, but on account of the field evidence Krejci believes that tectonic thrust from the Carpathian mountain-building movements cannot have been the effective force, and therefore argues for upthrust due to the downward thrust of the sedimentary cover. The upthrust is made possible by the plasticity of the salt, clay, and marl, and by the lower specific gravity of the salt in comparison to the surrounding sediments, and it is aided by erosion of the crests of the anticlines with exposure of the plastic underlying formation and by deposition in the intervening synclines.

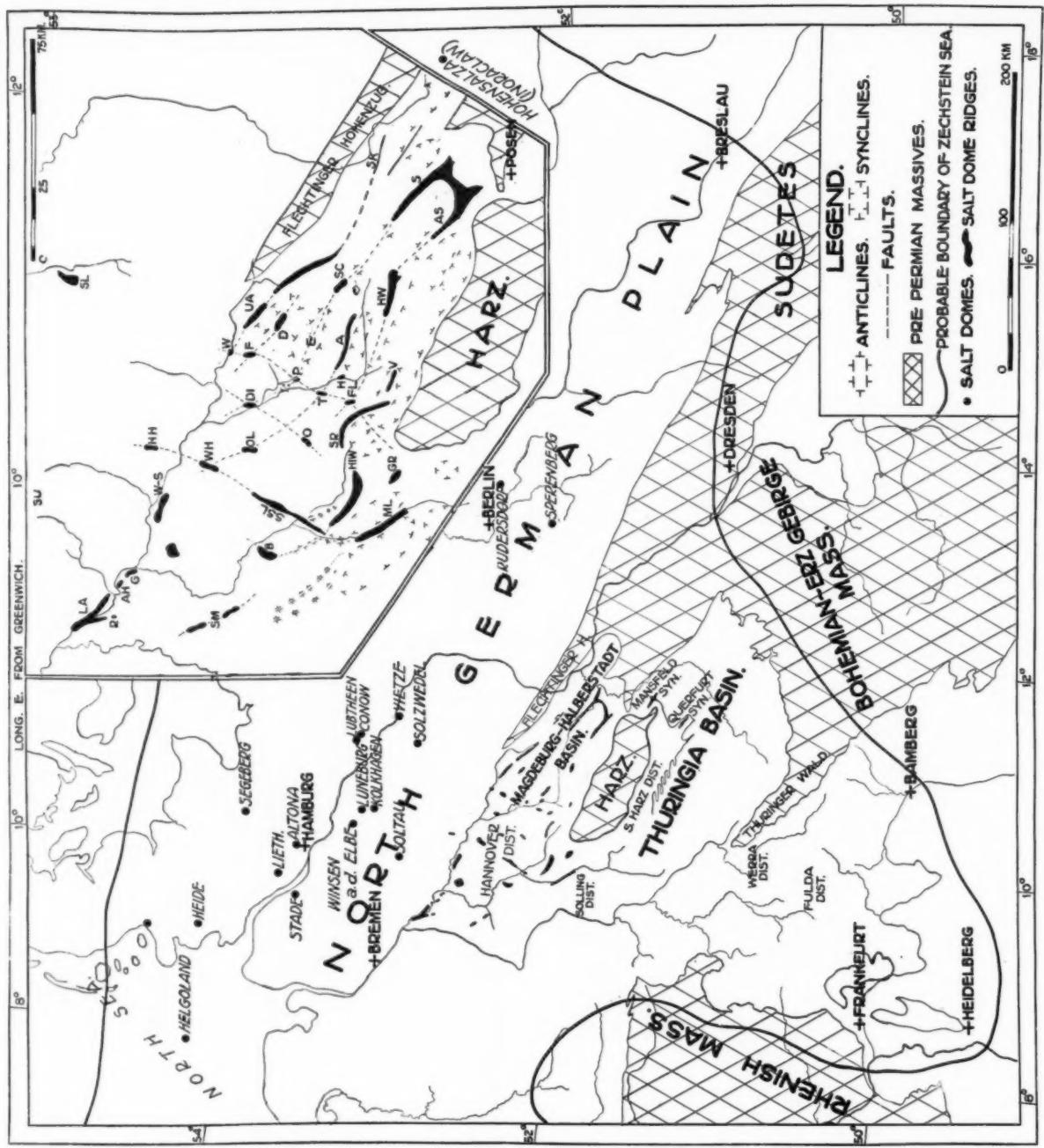
The Roumanian domes are not so well known as the American domes. They occur in a structurally complicated setting, and it is not easy to disentangle the salt-dome structure from the tectonic structure; furthermore, exploration has not gone so far as on the American domes. The Roumanian salt-dome geologist possibly may have more to learn from the American salt domes than the American salt-dome geologist has to learn from the Roumanian domes. The occurrence of the American domes in a region of tectonic quiescence suggests that tectonic thrust cannot have the importance postulated by Mrazec, and the characteristic relative excess of density of the upper part, at least, of the American salt core and cap, in comparison with the surrounding sediments, suggests that isostatic thrust is not

competent by itself to explain the upthrust. The following features of the Roumanian domes, however, are suggestive in connection with the problems of the American salt domes: (a) the resemblance of the Roumanian domes to the American domes, if allowance is made for the effects of the complicated structural setting in which the Roumanian domes are found; (b) the occurrence of the domes in pronounced anticlines; (c) the occurrence of the salt and Salifere marls and clays as diapir-type cores in the anticlines; (d) the alignment of the anticlines along structural, chiefly anticlinal, lines; (e) the effective control of the structural setting on the form and occurrence of the domes.

TRANSYLVANIAN SALT DOMES

The Transylvanian group of salt domes occur in the Miocene-Pliocene basin inclosed within the bow of the Carpathian arc and the Apusen Mountains in the former Hungarian province of Transylvania, now ceded to Roumania. The Transylvanian basin consists of relatively flat-lying Miocene and Pliocene beds with a gentle regional dip to the center of the basin. The beds, however, are folded into a series of anticlines and synclines along axes tending to have a north-south strike, but also tending to conform somewhat to the edge of the basin. As the area is not known to be petroleum-bearing, and as there has been very little exploration for oil, little is known about the domes except the few in which salt mining is carried on. The known salt domes, as given by Papp, are shown on the map (Fig. 2). Inward from the edge of the basin there are other structural domes, some of which are suspected to be salt domes.

The data available in regard to the characteristics of the Transylvanian domes are scanty. The well-known Maros-Ujvar salt dome is elliptical in outline, with major and minor axes 2,700 and 1,500 feet, respectively. The salt core is said to have steep, or even slightly overturned, flanks, and the salt has dark banding which stands nearly vertical. At many of the domes, according to Papp, the flank beds have a quaqueversal dip away from the dome. In one case, according to a personal communication from Dr. Hugo Böckh, the dacite tuff can be traced with normal dip under the salt core. From the map (Fig. 2) it can be seen that the salt domes tend to occur on the anticlinal lines.



SKETCH MAP OF THE GERMAN SALT DOMES, WITH A LARGER SCALE MAP OF THE MAGDEBURG-HALBERSTADT BASIN AND OF THE HANOVER DISTRICT
 (Compiled from papers by Everding-Einecke, Lachmann, Seidl, Stille, from Lepsius' geologic sheets, and from the Erläuterung maps of the German Geologic Survey)

A, Asse	G, Gretzheim
A, Anden	GR, Gr. Rhiden
B, Aschersleben	HH, Hohenburg
B, Benthe	HH, Habilshorst Höfer
B, Dornum	HW, Hildesheimer Wald
D, Diddere	HW, Hoy Wald
E, Elm	HW, Lower Aller
F, Fallersleben	ML, Middle Leine
F, Flachstöckheim	O, Oslebshausen
	SS, Salzau
	Su, Soltau
	T, Thiede
	UA, Upper Aller
	Vi, Vienenburg
	WH, Wathlingen-Hainjürgen
	WS, Wies-Steinförde
	St, Salzgitter

In the fragmentary state of knowledge of the Transylvanian salt domes there are only three points which are suggestive in connection with the problems of the American salt domes: (1) that the Maros-Ujvar dome resembles an American salt dome with its crest eroded; (2) that the salt domes tend to occur on anticlinal lines; and (3) that the salt domes occur in a region which has been subjected to moderate folding, but to no such thrust as the area of the Carpathian salt domes.

GERMAN SALT DOMES

The German salt domes are a phase of the North-German Zechstein salt deposits. These salt deposits were laid down in depressions of the basin which, in Zechstein times, extended from Netherlands on the west across Northern Germany into Poland on the east, and from Southern Denmark on the north to Munster, Frankfort-am-Main, Mamberg, Dresden, and Breslau on the south (Plate 27). Formerly, these salt deposits extended as a more-or-less continuous series of beds over wide areas, but by post-Permian tectonic movements the area in which they occur was broken up into several tectonic basins: the Magdeburg-Halberstadt basin, the Thuringia basin, and the Rhone basin. From the intervening areas of the Thüringerwald, Harz, and Flechtinger Höhenzug, the Zechstein beds have been eroded, but in the basins the salt deposits normally lie buried under the Triassic, Jurassic, and, in part, under the Cretaceous. To the north of these three basins the salt deposits in the Hannover area and in the area of the North German plain normally lie deeply buried under the Tertiary as well.

The salt deposits are composed of a series of formations that is very uniform over a wide area. The respective normal stratigraphic sections for the Werra district, the Middle Leine Valley district, the Stassfurt district, and the Hanover district are given in Table III.

According to the available literature, differentiation of the salt series in the Werra district into formations correlative with those of the standard Stassfurt series seems impossible, and the only formations which can be correlated between the Werra district and the other three districts are the overlying Upper Zechstein clays and the underlying Lower Zechstein. Throughout the other three areas the

TABLE III
STRATIGRAPHIC SECTIONS OF THE GERMAN SALT DEPOSITS

Werra District*	Normal Middle Leine Valley†	Normal Stassfurt	Normal Hannover‡	Remarks
Upper Zechstein clays, 16-20 m. Dolomite, 15-25 m.	Upper Zechstein clays, 20 m. "Youngest" rock salt, 50-60 m. "Pegmatitic" anhydrite, 1-2.5 m.	30 m. (20-30 m.) 30 m. (50) 1 m. (1-5)	0 m. 30 m. 1 m.	Massive red-clay bed with anhydrite nodules and a bed of anhydrite at the base Rock salt Anhydrite with scattered intergrown salt crystals and with a graphic texture somewhat like pegmatite
Lower Zechstein clays, 35-65 m.	"Red salt clay," 20-25 m. "Younger" rock salt, 145-70 m. "Main" anhydrite, 20-40 m. "Gray salt clay," 4-5 m. "Older" potash beds, 8 m.	10 m. (5-15 m.) 50 m. (100-50 m.) 40 m. (10-50 m.) 7 m. (4-10 m.) 30 m. (30-40 m.)	"Younger" salt, 60 m. Younger syncline zone, 15 m. Kieserite zone, to m. "Younger" salt, 70 m. 40 m. 7 m.	Massive red clay with anhydrite nodules Rock salt with some polyhalite and anhydrite A massive bed of anhydrite without traces of clay, dolomitic marl, and anhydrite in places carrying marine fossils very widespread and very uniform Fifty-five per cent carnallite ($KCl \cdot MgCl_2 \cdot 6H_2O$), 26 per cent rock salt, and 17 per cent Kieserite ($MgSO_4 \cdot H_2O$), on the average Rock salt and kieserite Rock salt with anhydrite bands averaging 94 per cent rock salt and 6 per cent anhydrite and clay Anhydrite with intercalations of bituminous dolomitic beds and of one or two ten-to fifteen-meter beds of rock salt
Lower Zechstein	Rock salt with two potash beds, 200-300 m. "Older" rock salt, 70 m. Lower beds not exposed	10 m. (20-30 m.) 250 m. (100-300 m.) Lower 70-100 m., anhydrite Zechstein, 4-10 m. Limestone Zechstein, 0.5-4 m., conglomerate	30 m. 10 m. Lower beds not exposed	

* After Everding.

† After Renner.

‡ After Seidl.

§ Figures with parentheses after Everding (1909); without parentheses, after Seidl (1921).

normal section varies from district to district chiefly in the thickness of the individual members and in the presence in the Hanover district of a potash zone in the "younger rock salt" in addition to that at the top of the "older rock salt." The general lithologic character of each of the formations is remarkably constant, and the older rock salt and the younger rock salt are sufficiently different in petrographic character, so that they can be distinguished from one another readily. This differentiation of the German salt series has been of the utmost importance in studying the German salt domes, for by means of it the German geologists have been able to work out with great precision the enormously complicated internal structure of the salt domes.

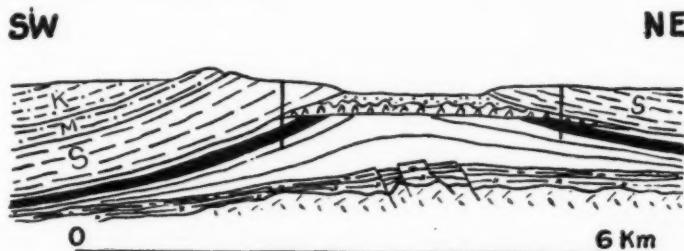


FIG. 6.—Section across the northwest end of the Schmücke-Finne salt-dome ridge (example of Stassfurt type). After Schlafke.

The German Zechstein salt deposits occur in the following structural types:¹

1. Normal, unaltered sedimentary beds, nowhere exposed
2. Sedimentary beds in essentially normal position but altered by
 - a) Squeezing out of the "Older rock salt" and less often of the younger rock salt in the synclinal areas between the salt ridges
 - b) Solution, at the outcrop of the Zechstein along the edge of the Paleozoic arches
3. Beds showing reduplication but still having the aspect of normally lying sediments
 - a) Werra, Fulda, South Harz districts
4. Salt domes
 - a) Stocklike salt domes
 - b) Salt-dome ridges

¹ Essentially after Seidl—Ref. 19.

On the basis of form and structure, the following types of salt domes and salt ridges can be recognized:

a) Stassfurt type (Fig. 6).

Broad anticlinal zones with broad cores of the older rock salt; the older potash beds occurring on the flatly dipping flanks; the crest of the salt core long since dissolved away; the salt core 700-1,000 meters (2,300-3,300 ft.) thick.

b) Asse type (Figs. 7 and 8).

Small, more fissure-like zones with scantily faulted salt deposits not completely piercing the overlying beds; the "Older beds" in places forming stock-like masses; the crest of the salt core only slightly eroded away; the salt core 1,300 meters (4,200 ft.) thick.

c) Leine type (Fig. 9):

A broken anticline with salt squeezed up between the two flanks.

d) Hannoverian type (Figs. 10 and 11):

Stocklike salt cores with complicated internal folding and flanked by strongly dragged, and in part overturned, lateral beds; the salt core 600-3,000 meters (2,000-10,000 ft.) thick. The Hanoverian type is very similar in general form to the American salt domes and differs from them chiefly in that there is usually one dimension longer than the others.

Like an American salt dome, the characteristic German salt dome, of any of the four types, is composed of a salt core, with a gypsum cap and with flank beds dipping away from the salt core.

The salt core, in a very large number of the salt domes, is well exposed in the workings and borings of the various potash mines. Detailed study of the salt formations forming the salt cores has therefore been possible and has shown the presence of the characteristic section which extends with relative constancy throughout the domes. By means of this section, and especially certain members of it which, although thin, are persistent in spite of folding, it has been possible to work out with great delicacy the very intricate folding which is present in many of the salt domes. Although the minor folding in the Stassfurt and Asse types may be complicated, the general pattern of the folding is of a relatively simple anticlinal type (Figs. 6, 7, and 8). The Leine Valley type is remarkably similar to case "C" in Mrazec's explanation of the formation of a diapir fold by under thrusting (see Figs. 4 and 9); and as postulated by him, the salt core has been rolled over, with a result, in this case of fairly complicated internal folding. The salt cores of the Hannover-

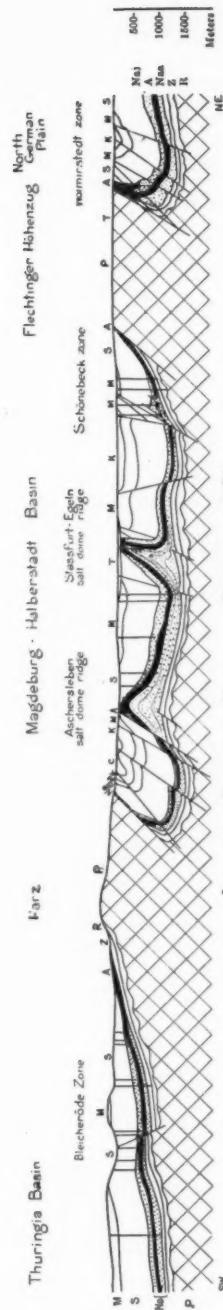


FIG. 7.—SW.-NE. structure section from the Thuringia basin across the Magdeburg-Halberstadt basin showing the structural relations of the Aschersleben and Stassfurt-Egeln salt-dome ridges. (Partly after Everding and Geinecke; the Stassfurt-Egeln ridge modified after Schünemann; the Aschersleben ridge and Schönenbeck zone after Seldi.)

T = Tertiary, C = Cretaceous, K = Keuper, M = Muschelkalk
 S = Buntsandstein, Na = Zeichstein salt series $\begin{cases} N_2 & \text{"Younger" salt series} \\ A & \text{"Main anhydrite" salt series} \\ Z & \text{Middle and Lower Zeichstein, } R = \text{Rotliegendes} \\ P & \text{Pre-Permian} \end{cases}$

rian type show a most complicated internal structure. The older salt seems to have broken through the apparently less plastic younger salt series, and in many places to have overturned and thrown it back. Figure 12 shows an example of the very complicated folding that has resulted. It should be noticed that the apparent anticlines of the section in reality are overturned synclines, and the apparent synclines, overturned anticlines. In the case of the Benthe

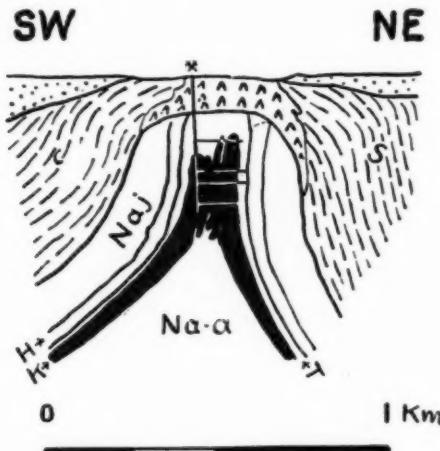


FIG. 8.—Section across the Stassfurt salt-dome ridge (at this point an example of the Asse type). After Schünemann. *S* = Buntsandstein, *Maj* = "Younger" salt series, *H* = "Main" anhydrite, *T* = "Gray, salt" clay, *K* = "Older" potash series, *Na-a* = "Older" salt series.

salt dome, Stier has been able to map with great detail the folding shown by the salt and has been able to show the presence of two sets of folds, the one, Hercynian (NW.-SE.) in strikes; the other, Rhenish (NE.-SW.) in strike (Fig. 13). The effect of the Hercynian folding, furthermore, is stronger above the 600-meter level, and decreases with increasing depth, while the reverse is true of the Rhenish folding.

The vertical thickness of the salt core, especially in the salt domes of the North German plains, is great. The following are depths at which wells stopped in the salt without having encountered

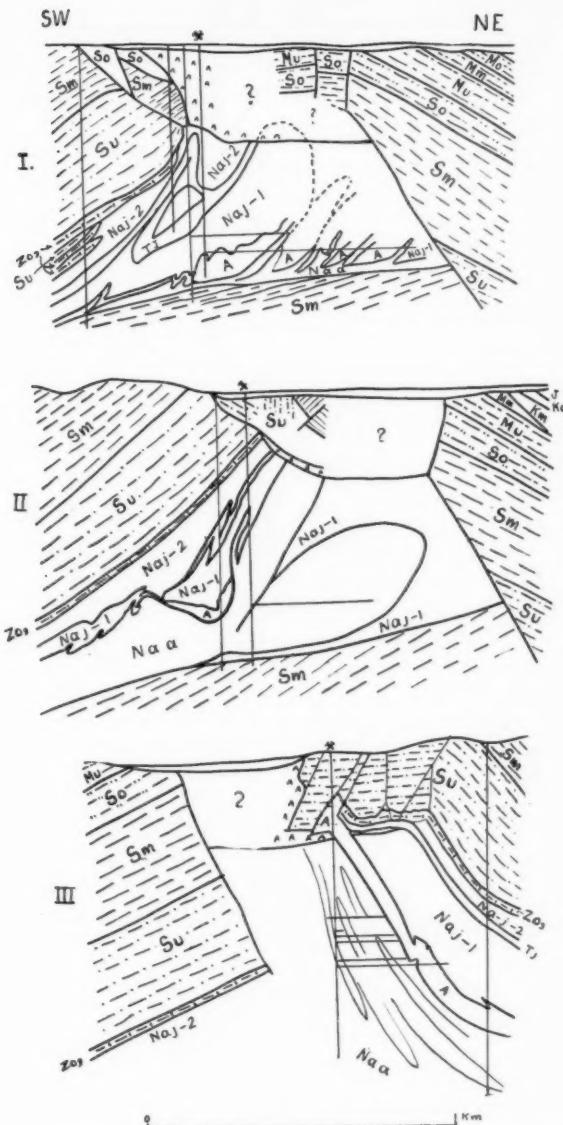


FIG. 9.—Sections across the Middle Leine Valley anticline near Alfeld. After Renner. Section I, 7.5 km. NW.; and section III, 11 km. SE. of section II.

Mo , Mm , Mu = Upper, Middle, Lower Muschelkalk
 So , Sm , Su = Upper, Middle, Lower Buntsandstein
 Zo = Zechstein clays
 $Naj-2$ = "Youngest" salt series
 Tj = "Red-salt clay" and "Pegmatite" anhydrite
 $Naj-1$ = "Younger" salt series
 A = "Main" anhydrite
 $No-a$ = "Older" salt series

the underlying formations: Hildesheimer Wald dome in the Northwest Harz foreland:

	Meters	Feet
Sülberg boring.....	1,350	(4,431)
Salzdetfurth No. II.....	1,400	(4,595)

SALT DOMES OF THE NORTH GERMAN PLAIN:

	Meters	Feet
Sperenberg.....	1,390	(4,562)
Salzwedel Boring No. IV Gustritz.....	1,408	(4,621)
Lubtheen.....	1,204	(3,952)
Altona, Lieth boring.....	1,338	(4,391)
Wietze-Steinförde Prinz Adelbert No. IV.....	1,613	(5,294)

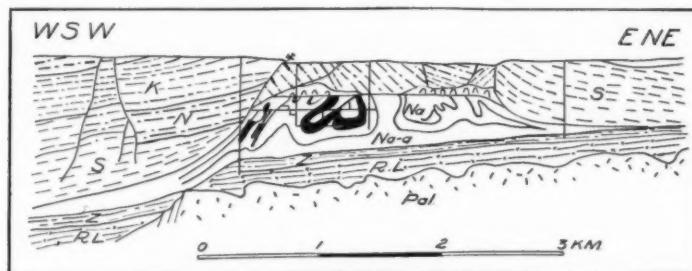


FIG. 10.—Section across the upper Aller salt-dome ridge (example of Hannoverian type salt-dome ridge). After Schmirrer and Seidl.

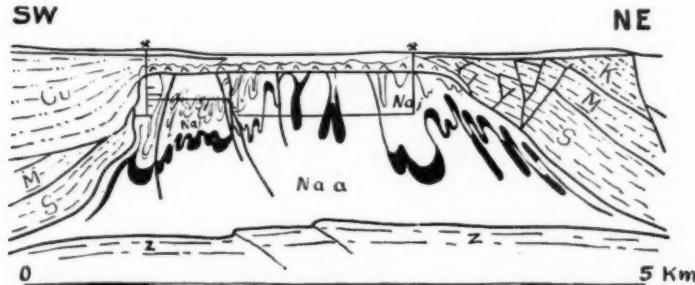


FIG. 11.—Section across the Benthe salt dome through the Deutschland and Ronnenberg mines. After Stille and Seidl. (Example of Hannoverian type salt stock.)
Cu = Lower Cretaceous, *K* = Keuper, *M* = Muschelkalk, *S* = Buntsandstein
Na-j = "Younger" salt series, *Na-a* = "Older" salt series, \wedge = gypsum cap

As the Prinz Adelbert encountered the salt at 109 meters, its record of salt from 323-5,294 feet surpasses the American record, made by the Texas Company at Humble, of salt from 1,340 to 4,400 feet (408-1,340 m.) in a well on top of the dome, and 2,342-5,410 ft. (713-1,648 m.) in a well on the flank.

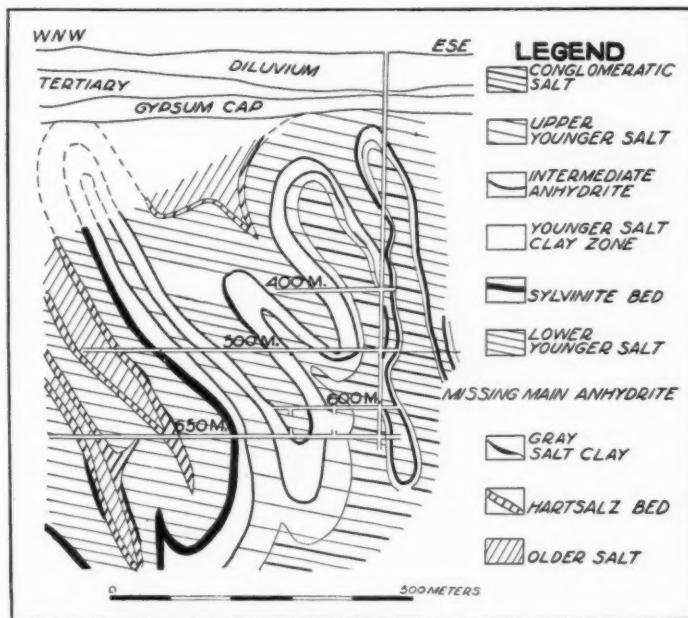


FIG. 12.—Section through the Riedel mine at Hänigsen, showing in detail the complicated folding of the salt series. After Stille.

One of the most striking features of this complicated folding is the extreme plasticity of the salt series as a whole, with, however, very great differences in the plasticity of the various members. The massive salt beds show a plastic reaction to deformation, while the "main anhydrite," the "gray salt clay," and the "red salt clay," show a rigid reaction: that is, under deformation, the plastic salt beds bend and stretch, while the rigid beds fracture and break. Where the folding is complicated, the main anhydrite and the gray

salt clay commonly have been torn apart; in domes of the Stassfurt type they are found only in the synclines and flanks of the anticlines;

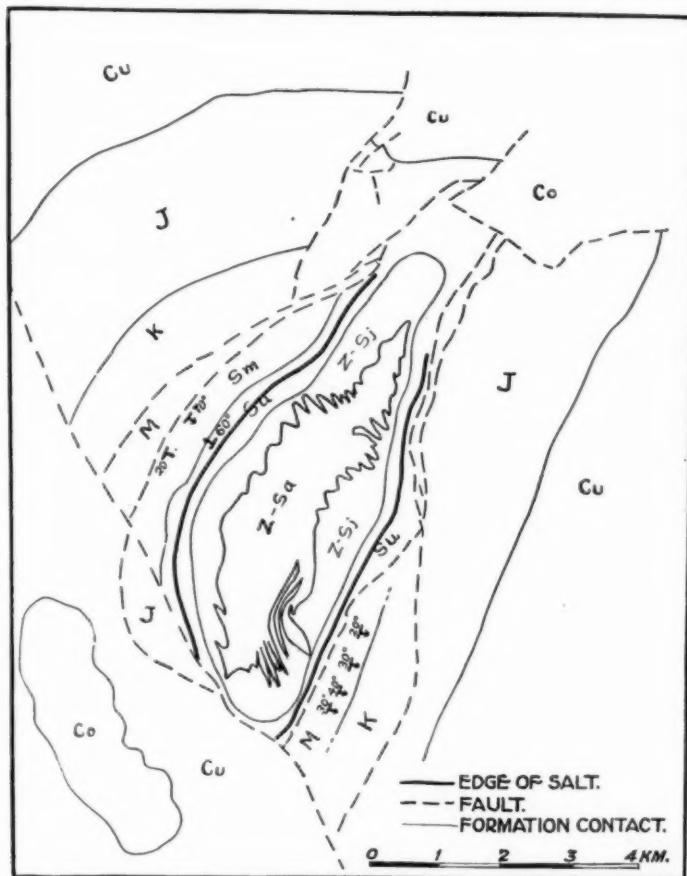


FIG. 13.—Sketch map of the Benthe salt stock. Surface geology after Stille—contact between Z-Sj and Z-Sa taken from 500-meter level in mines, after Stier. Quaternary and Tertiary cover omitted, Co=Senonian and Emscher (Upper Cretaceous), Cu=Marine Lower Cretaceous, J=Jurassic, K=Keuper, M=Muschelkalk, Sm=Middle Muschelkalk, Su=Lower Muschelkalk, Z-Sj="Younger" salt series, Z-Sa="Older" salt series.

and in the Hannoverian type of domes, they are found only in the troughs of the synclines and the crests of anticlines. Figure 12 shows an example of the extremely plastic reaction of the salt deformation.

The gypsum cap in a general way appears to resemble the cap of the American salt domes. It lies on the nearly level top of the salt core and has a thickness of a few centimeters up to 100 meters (0-300 ft.). The cap grades into a mantle that extends well down the flanks of the dome. The cap is composed predominantly of gypsum, in some cases mixed with clay or material from the overlying beds. In a few cases the base of the cap is composed of anhydrite rather than gypsum. The lower portion of the cap tends to have a fine, nearly horizontal, bedding, while the upper portion tends more toward a breccia. From the suite of specimens seen by the writer at the Technische Hochschule in Hannover, the gypsum and anhydrite of the cap of the German salt domes has a confused and irregular texture and lithologic structure that contrasts strongly with the even, uniform, coarsely crystallized selenite and the macroscopically massive, even, uniform saccharoidal anhydrite of the American domes. The origin of the cap rock in the German domes is attributed by the German geologists to regeneration and cementation of the residual anhydrite left behind in the solution of the top of the salt core. As can be seen from the discordant relation of the top of the salt to the folding, a very large amount of salt has been removed from the top of the salt core. As the salt contains a notable amount of anhydrite (the older rock salt, 5-6 per cent) in addition to the intercalated beds of anhydrite, the residual theory forms a perfectly plausible explanation of the gypsum cap of the German salt domes.

The flank beds dip away from the axis of the salt core as in the American domes, but there is considerably more of a tendency toward concordance between the flank beds and the edge of the salt core. The salt domes of the Stassfurt type and of the Asse type are not true diapir folds. The salt has arched up the overlying beds, or the salt and the overlying beds have been arched up together, but the salt core has not broken through them. Many of the salt domes of the Hannoverian type seem not to be diapir folds, but to have concordant relations between the flank beds and the edge of the salt

core. In the case of many other of the domes of the Hannoverian type, as, for example, Wietze-Steinförde, Hänigsen-Wathlingen, Oelsburg (N. Peine), and probably Lübtheen and Salzwedel, the salt core is at least partially bounded by peripheral faults, cuts discordantly across the edge of the upturned flank beds, and stands in true diapir relation to them, similarly as in the case of the American salt domes of the Gulf Coast. The flanks of all the types are characterized by more or less faulting. The flanks of the following Hannoverian type of dome are overturned: Steinhuder Meer (SW. side), Hope Lindwedel (SW., NW., NE. sides), Benthe (NW. and S. sides), Sarstedt-Sehnde (NW. side), Sehnde-Lehrte (NNW. side), Fallersleben (W. side), Middle Leine Valley (W. side), South half, Upper Aller (NE. side), N. $\frac{1}{2}$ Upper Aller (SW. side), Hohensalza (probably W. and E. sides).

Relations of transgression and angular unconformity are present in the flank and supersalt beds, and, according to Stille, folding has taken place as follows in the salt domes or in the salt-dome lines: Pre-Cretaceous (Cimmerian) folding:

1. On the Rhenish-striking salt-dome line, Sehnde-Lehrte, Hänigsen-Höfer, Bardenhagen, Lüneburg
2. On the Hercynian-striking anticlines of the Calenberg and Asse axes

Intra-Cretaceous:

1. On the Rhenish-striking Hänigsen-Wathlingen dome.
2. On the Hercynian-striking Lower Aller salt-dome ridge

Early Tertiary:

1. On the Rhenish-striking Sehnde-Lehrte, Hänigsen-Wathlingen salt-dome line and the Benthe salt dome.
2. On the Hercynian-striking Lower Aller salt-dome ridge and Calenberg axis.

Late Tertiary:

1. On the Rhenish-striking salt domes, Hänigsen-Wathlingen, Bardenhagen-Kolkhagen, and Wünhow-Lüchow.
2. On the Hercynian salt-dome line north of Steinhuder Meer.

The type and character of the individual salt domes and the pattern of their arrangement reflect strikingly the setting in which the salt domes are found. The most important elements of this tectonic setting are: the Bohemian mass with its two tectonic Peninsulas of the Harz and the Flechtinger Höhenzug, the Hercynian system of fractures (NW. and W.-NW.-SE.) which charac-

terize Central Germany and which control the form of the Harz and the Flechtinger Höhenzug, the Rhenish mass, and, to the north of the Bohemian and Rhenish masses, the North German plain, with its mass of sediments thickening northward.

Inclosed between the Harz and the Flechtinger Höhenzug is the tectonic Magdeburg-Halberstadt basin, which was formed by diastrophic movements in post-Permian times.

The tectonic pattern of the salt domes is what we should expect as a result of the collapse and slight lateral compression of such a basin, that is, a series of long anticinal Hercynian axes conforming in direction to the sides of the basin. As the stratigraphic thickness of the overlying sediments above the salt formations in the basin was only 600 to 800 meters and was composed of relatively more consolidated sediments than the Tertiary rocks of the North German plain, the salt domes characteristically are of the Stassfurt and Asse types, in which the overlying beds have not been broken through by the salt, but have been arched with it.

In the North German plain, immediately off the front of the Harz and Flechtinger Höhenzug, the Hercynian (W.NW.-E.S.E.) strike of the salt-dome axes of the Magdeburg-Halberstadt basin gives way to a predominately Rhenish strike (N.NE.-S.SW.). There are three well-marked Rhenish lines of salt domes: the Flackstöckheim, Theide, Rautheim, Fallersleben, Weyhausen line, the Oelsburg-Oelheim line, and the Sarstedt-Sehnde-Lehrte, Hänigsen-Wathlingen, Habighorst-Höfer line, in which the Sarstedt-Sehnde-Lehrte dome is itself a long narrow salt-dome ridge with a Rhenish strike. In addition, the isolated domes, Benthe, Didderse, Salzwedel, Kolkhagen, and Lübtien, show a Rhenish strike or traces of a Rhenish strike. It is as if the North German plain were being thrust against the northwest edge of the Bohemian mass, as marked by the line of the front of the Harz and the Flechtinger Höhenzug. In this zone of predominately Rhenish strike, however, the influence of Hercynian strike also is evident. Many of the salt domes seem to mark the intersection of a Rhenish line of uplift with the prolongation of one of the Hercynian lines from the Magdeburg-Halberstadt basin (Plate 27). In many of the domes, also, as, for example, Benthe (Fig. 13), the salt core shows the effects of both

Rhenish and Hercynian folding. In the case of the Benthe dome, the effects of the Hercynian folding are more pronounced above the 600-meter level, and the effects of the Rhenish become increasingly pronounced with increasing depth below the 600-meter level. According to Stier's interpretation, it is the Rhenish forces of folding which have provided the predominating motive force for the upthrust of the salt core.

The Hercynian lines again seem to control the alignment of the domes to the north and west of the Hanoverian area of predominate-ly Rhenish strike. On the northeast there is the well-marked line of the Lower Aller, with both the Wietze-Steinförde dome and the Lower Aller (Verden-Kirchwahlingen) domes themselves showing a marked Hercynian strike, and there is also the Hercynian-striking Steinhuder Meer dome. To the north, there is the Lower Elbe group of domes, apparently forming an elongated area with a Hercynian strike. And it is in the prolongation of this zone that the two lone domes near Berlin occur. In the Lower Elbe salt-dome area it is possible to line up the individual salt domes along several possible salt-dome lines; as, for example, Helgoland, Stade, Winsen a.d. Elbe, Lüneburg, or Kolkhagen, Salzwedel, and Sperenberg, or the line Heide, Lieth, Altona, and possibly Lüneburg and Sperenberg, or the slightly less probable line, Segeburg, Lübleen, Conow, Wietze, and possibly Sperenberg. As was first suggested by Bey-
schlag and later emphasized by Stille, Seidl, and others, these domes probably reflect the prolongation of the series of folds which, in South Hannover, are exposed at the surface, but which in the North German plain are deeply buried under the Tertiary cover.

The cause of the upthrust of the German salt domes is attributed by the German geologists to tectonic forces. Stille, in his papers on the Hannover district and on injective folding, traces the pattern of the folding in the Hannover district and ties together the salt domes of the North German plain, the salt-dome ridges of South Hannover, and the *graben* of Southern Hesse in a single Saxon system of folding, of which the motivating force is tangential thrust. Seidl, in some of his discussions, seems to favor vertical isostatic thrust as the motivating force, but the diagrams in his paper on salt-dome exploration seem to teach the lesson of tangential thrust, and he definitely

attributes one set of domes to underthrust. Renner's sections of the Middle Leine salt-dome ridge seem definitely to show tangential thrust (resulting in overthrust) as the motivating force. Stier, in his work on the Benthe salt dome, shows the clear impress on the salt core of folding in the same two directions which control the alignment and strike of the salt domes and salt-dome ridges. Lachman and Arrhenius, however, advocate the theory that the upthrust of the salt is due to isostatic forces resulting from the lesser specific gravity of the salt in comparison to the overlying formations. Few of the German salt-dome geologists seem to follow Lachman and Arrhenius far, but many emphasize the importance of the vertical pressure of the overlying sediments upon the salt. There seem to be no advocates among the German geologists for any of the various American theories of salt domes, the volcanic theory, the theory of deposition from ascending brines, the evaporation of brines by escaping gas. The impression that the writer has gained from the discussions, diagrams, and sections of the German domes is of a relatively mobile substance, the salt yielding under pressure by plastic flow rather than by fracture, or by simple bending in the case of the ordinary sediments.

Significant points in regard to the German salt dome in connection with the American salt-dome problems are: (1) The salt occurs in a series of normal sedimentary beds which can be recognized in a practically constant section throughout the salt domes. (2) The Middle Leine salt-dome ridge and the salt-dome ridges of the Magdeburg-Halberstadt basin are plainly the result of the tectonic deformation of the sedimentary salt series. (3) The salt domes of the North German plain are so intimately connected with the salt domes of the Magdeburg-Halberstadt basin and with the Middle Leine salt dome, and there is such a complete transition between them, there seems to be no reasonable doubt that all the German salt domes have been formed by the same forces, although, in the different areas, the domes may have been cast in slightly different molds. (4) Where the cover above the salt series is only moderately thick and composed of only moderately consolidated beds, the salt dome tends to take the form of an anticline with the flanks of the salt concordant with the flank beds; where the cover is thick and com-

posed of weakly consolidated sediments, the salt core tends to pierce the cover and form a diapir fold. (5) In the North German plain, the flat-lying (mother) salt series of the inter-salt-dome areas have not been found, for the reason that the stratigraphic horizon at which they occur is buried to great depths. (6) The salt domes seem to be due primarily to the fact that massive salt deposits possess a mobility far above that of other sediments, and yield to thrust by plastic flow. (7) The salt domes of the North German plain, such as the Benthe, Wathlingen-Hänigsen, Habighorst-Höfer salt domes, and all the salt domes of the Lower Elbe are very similar to the American salt domes and do not differ from them in any essential way.

CONCLUSION

In the light of knowledge now at hand it is evident that the salt domes of Texas and Louisiana represent essentially the same type of geologic structure as the German and Roumanian salt domes. Due to the difference in the geologic setting of the domes of the respective countries, the American domes differ from the Carpathian-Sub-Carpathian domes and from the German domes in the form which this type of structure has assumed, but where the geologic setting is the same, as, for example, in the North German plain, very closely similar forms have been assumed. In the light of this innate similarity of structural pattern it is evident that the American salt domes probably have been formed by the same general forces acting according to the same general laws that formed the German and Roumanian salt domes.

It is evident that some of the rather characteristic features of the American salt domes are not essential features of salt-dome structure. Although not present on all domes, the limestone-gypsum-anhydrite cap is distinctly characteristic of the American salt domes. Yet the Roumanian domes are without any such cap and the gypsum cap of the German domes seems possibly to be different in origin from the American cap rock. Native sulphur is characteristic of the cap rock of a large number of the American domes, and on some of the domes is present in large quantity, but no sulphur is reported from either the Roumanian or the German salt domes. The accumulation of considerable quantities of petroleum is characteristic of a

large number of the American and Roumanian domes, but only minor amounts of petroleum are found around the German domes. On the problems of such features of the American domes little or no light is shed by the knowledge available in regard to the Roumanian and German domes.

A minor feature on which light is shed by knowledge of the German salt domes is the origin of what the writer calls "secondary mounds," "subsidiary crests," and "salt spines." The small mound in the northwest quadrant of the Vinton salt dome is a secondary mound. The more marked crests of the Damon Mound salt-dome mound are subsidiary crests. The crest of the salt core of the New Iberia dome is a salt spine. On the basis of physiographic study of Vinton, Barbers Hill, Big Hill-Jefferson, and Damon Mound, the writer became convinced that secondary mounds are due to secondary upthrust affecting only part of the salt core, and that the subsidiary mounds are either due to secondary upthrust or to differential upthrust with several centers of maximum movement. The belief was strengthened by a study of the structure of the New Iberia dome, where a spine of salt rises 1,200 feet (360 m.) above a much broader salt table. The sections of the Hannoverian type of salt domes (Figs. 10 and 11) seem to show that the older salt has streamed up through the overlying younger salt along several centers or axes of movement. The assumption would seem to be warranted that rate of upward movement should be greater along such axes or centers than along the interaxial lines. Such differential movement, if expressed at the surface, should produce a series of subsidiary mounds such as are present at Damon Mound. It would also seem not unreasonable to expect that later movement of minor amount might take place along one of these axes or centers and not along the others. Such movement would tend to form salt spines, and secondary or subsidiary mounds.

In connection with the more important problems, the following points seem to be evident:

Carpathian-Sub-Carpathian domes:

1. The salt domes are abnormal anticlines characterized by a core of the plastic salt and marl of the Salifere that has been intruded vertically upward into the overlying formations.

2. These anticlines tend to be on structural-trend lines that reflect the effect of the Carpathian tectonics.
3. The structural setting in which the domes occur has exercised a strong control on the form and occurrence of the salt domes.

Transylvanian domes:

1. The domes tend to occur on anticlinal lines.

German domes

1. The salt occurs in relatively normally lying sedimentary formation, in salt domes, and in salt-dome ridges.
2. The salt domes tend to occur on the extensions of the anticlinal axes of the salt-dome ridges, and on other anticlinal axes. The domes very commonly are at the intersection of anticlinal axes.
3. In the salt domes and salt ridges the salt forms the core. In some cases it is in concordant, and in the other cases in diapir, relations to the surrounding sediments.
4. The salt cores have been formed by deformation of the sedimentary salt formation, the salt of which has yielded by plastic flow and has been thrust or intruded into its present position.

From the other papers of the symposium on salt domes it can be seen that the flank beds of the American domes show the effects of very marked upthrust.

In the light of present knowledge it seems futile to predicate the origin of the American salt domes by any other method than by upward intrusion consequent upon, and coincident with, plastic yielding to deformation by a pre-existing salt mass, in all probability an originally flat-lying sedimentary salt bed. Especially does it seem futile since the opposing American theories are based on only very scanty positive evidence, or are based entirely on assumptions. The theory of the precipitation of the salt from ascending brines, whether by cooling or by evaporation by escaping gas, for example, is based on the assumptions: (a) of the possibility of an open channel leading upward through thousands of feet of gumbo and shale; (b) of the channel being kept open for geologic ages in soft, unconsolidated formations in which the driller has great difficulty in keeping a drill-hole open, even with the hole full of heavy mud; and (c) of the existence of ascending streams of brine. No such streams of brine are known to occur around the Gulf Coast salt domes. The presence of small brine springs at the surface would be of no significance in any case, since the German salt domes commonly happen

to be characterized by brine springs. The volcanic theory seems to have been proposed without any basis of positive evidence. There are, however, certain local relations in the Transylvania basin, and locally in south Texas, which have been interpreted by reputable geologists as pointing to a possible volcanic origin of salt domes. In the main salt-dome area of Texas and Louisiana, however, the salt domes are not accompanied by evidence of volcanic or even solfateric activity, and the Gulf Coast salt domes seem to be characterized by rather low geothermal gradients to the deeper horizons (about 100 ft. per 1° F.). In the German salt-deposits areas, where there has been volcanic activity there are no salt domes.

That the mother salt-beds of the American salt domes have not been discovered as yet is expectable on the basis of our knowledge of the German salt domes, and can in no way invalidate the theory of the derivation of the American salt domes from such beds. In the area of the German salt domes similar to the American salt domes, the mother salt-beds have not been reached, but there the inference is definitely warranted that they are present at depths which it is not now practicable to reach by boring.

What the motivating force of the intrusion is still remains an open question, even in the added light of the German and Roumanian salt domes. In the case of the Roumanian domes it is easy to call upon orogenic thrust. In Germany a mild orogenic thrust can be called upon, for there were repeated movements of mild folding. The general region in which the American salt domes occur has been one of the great geologic tranquility for a very great distance back into the geologic past. From the salt domes, especially from the Gulf Coast domes, it is far to any region which shows the traces of compressive folding. The static thrust of the overlying cover is not an entirely satisfactory acceptable alternative. It seems inadequate in comparison to the magnitude of the task. The German domes, furthermore, offer very pertinent evidence against the theory of vertical thrust in that there is a very prevailing tendency toward thickening of a bed at the crest of an anticline. Under merely vertically acting forces the crest of an anticline should be a point of thinning. Recrystallization approximately in place may well have occurred, but the evidence of the German domes

seems to be against any very considerable transfer of material by solution and recrystallization. Whatever the motivating force, the movement of the salt in the German domes seems to have been by plastic flow, and the force of growing under crystals recrystallization, therefore, seems a dubious motivating force.

In connection with the question of the alignment of the salt domes and the significance of alignment, the lesson of the German and Roumanian domes is that the salt domes are associated with anticlines rather than normal fault lines. To a certain extent the German domes indicate that domes of the American type occur at the intersection of anticlinal ridges. A most significant suggestion which the German domes offer is that the alignment of the salt domes of such an area as the Gulf Coast, with its enormously thick section of unconsolidated sediments, is controlled by the tectonic plan of the underlying basement.

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MAPS OF THE GERMAN GEOLOGICAL SURVEY SHOWING SALT DOMES

Salt Dome	Blatt	Lieferung	Year of Publication
Upper Aller	Gr. Twülpstedt	185	1914
Upper Aller	Weferlingen	185	1914
Upper Aller	Helmstedt	185	1914
Doorn	Süpplingen	185	1914
Fallersleben	Heiligendorf	185	1914
Flackstöckheim	Salzgitter	174	1912
Gr. Rhuden	Lamspringe	182	1915
Habighorst-Höfer	Beedenbostel	187	1915
Hänigsen-Wathlingen	Wathlingen	187	1915
Hänigsen-Wathlingen	Burgdorf i. H.	232	1921
Hildesheimer Wald	Sibbesse	182	1915
Middle Leine Valley	Gronau	127	1906
	Alfeld	127	1906
	Freden	127	1906
Lüneburg	Lüneburg	108	1912
Peine-Nord	Peine	232	1921
Salzgitter	Sazgetter	174	1912
Sperenberg	Sperenberg	243	1922
Stade	Staden-Hagen	106	1904
Stassfurt	Stassfurt	177	1913
Connecting zone between			
Stassfurt and Aschersleben	Güsten	177	1913
Vienenburg	Vienenburg	174	1912
Wietze-Steinförde	Winsen a.d. Aller	187	1915

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THE PERMIAN IN INDIA¹

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ABSTRACT

The general geographic provinces of India are named, the formations are shown in a table, the permian formations are briefly described, the presence of coal is noted, the widespread glaciation indicated, and the possibility of oil in the Permian discussed.

INTRODUCTION

Owing to their scientific, as well as economic, interest the extensive Permian deposits of India have received considerable attention by members of the Indian Geological Survey and are described in many excellent reports. The information set forth in this paper is therefore, for the most part, merely a brief review of what has already been published. Since many of the readers are unfamiliar with the general geography and geology of India, a brief outline is given previous to consideration of the Permian.

PHYSICAL ASPECT

Topographically, the surface of India is divided into three principal divisions, the border mountains forming the frontier on the northwest, north, and northeast, including the Himalaya and several lesser ranges; the Indus-Gangès Plain, a great alluvial plain adjacent to the border mountains, and the Great Peninsula, a region of low mountains and plateau topography.

The V-shaped portion of India extending far south into the equatorial waters of the Indian Ocean is commonly spoken of as the Great Peninsula. Most of its surface is upland and plateau, varied here and there by low mountains whose summits range from 4,000 to a maximum of nearly 9,000 feet above sea-level. The rocks are, for the most part, ancient crystallines, but in the western portion is an extensive region of basaltic lava, the Deccan Trap, and

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here the topography is characteristically of the table-land type, with numerous scattered mesas.

The triangular, V-shaped peninsular portion is separated from the border mountains of the west, north, and northeast frontier by the Indus-Ganges Plain, a great valley floor with a maximum eleva-

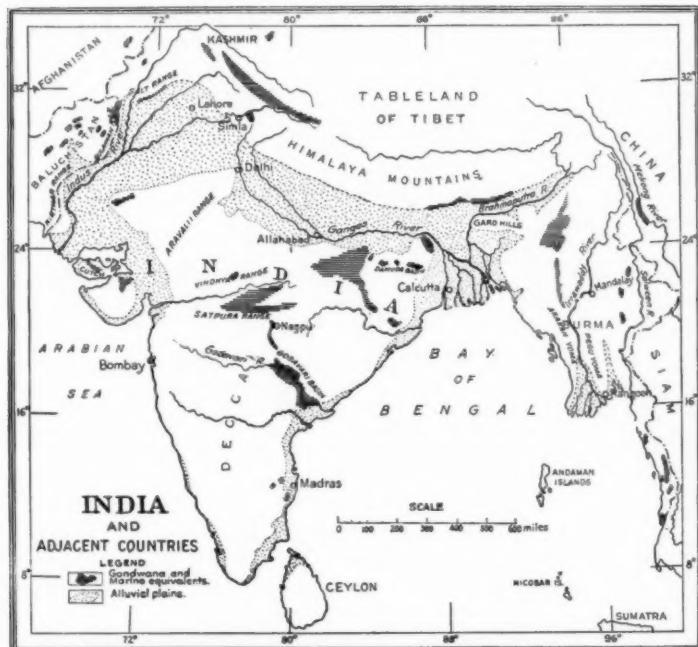


FIG. 1

tion of only a few hundred feet, extending across northern India from sea to sea. The western part is occupied by the lower Indus River system, and the eastern part by the Ganges and its confluent, the Brahmaputra.

The foothills of the Himalaya rise abruptly from the Indus-Ganges Plain, in successive parallel ridges of sandstone and conglomerate known locally as the Siwalik Hills, forming a belt 10 to 30 miles wide, with elevations ranging from 2,000 to 4,500 feet or

more. Back of these rise the great snowy ranges of the Himalaya, forming a barrier from Afghanistan east to the Chinese frontier.

GENERAL STRUCTURAL RELATIONS

The Peninsula shows every indication of having been a stable portion of the earth's crust since ancient times, the pre-Cambrian never having been submerged beneath the sea except locally and temporarily. Within this area scattered tracts of sedimentary rocks as old as the Cambrian have been subjected to but little structural deformation, lying nearly flat, nor have these strata undergone any considerable regional metamorphism, except in restricted tracts adjoining intrusive masses.

While the peninsular area throughout has been characterized by great stability, the opposite is true of the extra-peninsular region. During the late Paleozoic and throughout the Mesozoic this portion, although for much of the time beneath the sea, was undergoing constant but mild deformation in the form of tilting, warping, elevation, and subsidence. The profound folding and upfaulting that produced the Himalaya did not set in actively until late Tertiary, and has continued to recent times. Coincident with the southward up-thrust of the Himalayan mass came a gradual depression of the fore-land, producing the Indus-Ganges Plain, geosynclinal in structure, the mountainward side consisting of closely packed folds with much faulting, but the south side rising in gentle monoclinal slopes toward the peninsular area. Into this geosynclinal basin have been dumped vast amounts of sandy sediments carried by swift rivers issuing from the mountains, the thickness of the accumulations being estimated as at least 40,000 feet along parts of the Himalayan front. Coincident with the gradual piling up of these outwash deposits came progressive downwarping which kept the basin at or near sea-level throughout the Tertiary.

GONDWANALAND AND TETHYS SEA

From early Paleozoic to late Mesozoic time the peninsular land mass is believed to have been joined by a land bridge to Africa and Australia, forming a great equatorial continent known as Gondwanaland. To the north was an extensive mediterranean sea, the

Tethys, which, with only brief interruptions through local emergence, occupied the extra-peninsular portion of India from late Paleozoic to mid-Tertiary time, giving an almost continuous marine record at one place or another in the Himalaya.

DISTRIBUTION AND CHARACTER OF DEPOSITS

In the peninsular area the sedimentary record is far from complete, the Silurian, Devonian, and Lower Carboniferous being absent, and the Upper Carboniferous, Permian, Triassic, and Jurassic being represented by continental deposits which accumulated in numerous basins on the surface of Gondwanaland.

These late Paleozoic and early Mesozoic deposits are included in the Gondwana System, which is divided into the Lower Gondwana of Permo-Carboniferous and Permian age, the Middle, of Triassic age, and the Upper, of Jurassic and Lower Cretaceous age. The Lower Gondwana is of great economic interest as containing the most important coal fields of India. Through ages of denudation to which the peninsular region has been subjected, large tracts of Gondwana deposits have been removed, and those remaining owe their preservation to situation in downfaulted blocks and other structural depressions. Before the great structural valleys now occupied by the Indus, Ganges, and Brahmaputra were formed, sandstones, shales, and coal beds of the Gondwana probably were laid down in more or less continuous sheets extending all the way north to the outer Himalayan region. Segments of these strata are preserved here and there in fault blocks along the mountain front, and at one place near Darjiling coal of good quality, though greatly shattered, is found. There is, likewise, good reason for believing that large areas of the Gondwana with valuable coal beds are preserved under the 200,000 square miles of Deccan Trap in the western portion of the Peninsula.

The Gondwana formations have abundant plant and vertebrate remains which identify the beds as ranging in age from Upper Carboniferous to Lower Cretaceous. Some basins contain many thousands of feet of strata representing these several systems, while others have representatives of parts of one or more systems only. For instance, the basins in Cutch and Rajputana lack Permian and Triassic beds, but have a thick marine and fresh-water Jurassic

GENERALIZED SECTION IN THE PENINSULA

Upper Gondwana (Lower Creta- ceous)	Umia, Jabalpur, and Rajmahal series (thickness variable)	Massive sandstone, limestone, and carbonaceous shale, with a few coal beds; locally basaltic volcanic rock. Plant fossils with cycads and conifers abundant. Principal localities are Damuda Valley and Raj- mahal Hills, Satpura Range, Godavari Basin, and Cutch
Middle Gondwana (Triassic)	Maleri series (thickness variable)	Clays and thin sandstone beds of variable thickness, restricted to Satpura and Godavari basins. Plant fossils rare, fish and reptilian remains abundant
Middle Gondwana (Triassic)	Pachmari series (3,000 to 8,000 feet, Sat- pura range)	Sandstones and shales ferruginous; plant and vertebrate fos- sils. Maximum development in Satpura range, but also found in Damuda area and near Nagpur
Lower Gondwana (Permian and Upper Carboniferous)	Panchet series (1,500 feet, Satpura range)	Coarse sandstones, shales, and clays, red colors predominat- ing; no coal; vertebrate fossil bones abundant. Unconfor- mable contact with beds below
Lower Gondwana (Permian and Upper Carboniferous)	Damuda series (7,000 to 8,500 feet, Da- muda Valley)	Raniganj, 5,000 feet at type lo- cality in Bengal; sandstone, coarse to fine grained, and red brown and black shales with valuable coal beds, many of which in the Damodar Valley have been damaged by intru- sive dikes and sills of peridotite. Formation is rich in plant fos- sils, mostly cryptogams with a few spermatophytes
		Barakar, 2,000 feet at type lo- cality in Bengal; sandstones, coarse, soft, and usually white; also massive sandstones and carbonaceous shales with many valuable coal beds; "carbon- ate" iron ore deposits of local importance. Formation is widely distributed

GENERALIZED SECTION IN THE PENINSULA—Continued

Lower Gondwana (Permian and Talchir series (800 to Upper 1,000 feet) Carboniferous)	Karharbari, 500-600 feet; sandstones, conglomerate, and shales containing beds of coal; plant fossils numerous; formation widely distributed
	Talchir, 300-400 feet; sandstone, conglomerate, and boulder beds, the latter showing unmistakable evidence of glaciation; formation widely distributed

series overlain by marine Lower Cretaceous. This interfingering of marine and fresh-water formations illustrates the periodical encroachment of the Tethys Sea onto the margins of the Gondwana continent. In the Salt Range, and even as far north as Kashmir, are Permo-Carboniferous deposits of the fluriatile type comparable to the Gondwana facies of the Peninsula. These are, however, of insignificant development, and lie in the midst of a great marine sequence consisting of Permian, Triassic, and Jurassic strata.

GENERALIZED SECTION IN SALT RANGE

A generalized section in the Salt Range is described below as illustrative of the marine facies of the Permian:

	Thickness (Feet)
<i>Productus limestone series (Permian and Permo-Carboniferous):</i>	
Marls, sandstones, and sandy limestones.....	25 to 100
Limestones, marls, and dolomites, underlain by cherty limestone; crinoids, brachiopods, and other fossils.....	100 to 300
Sandy limestones and calcareous sandstones.....	50 to 100
<i>Speckled sandstone and boulder bed (Upper Carboniferous [?]):</i>	
Clays, bluish to gray, underlain by speckled and mottled sandstones, lower part fossiliferous.....	100 to 300
Boulder bed, consisting of glaciated boulders in a clayey matrix; igneous and metamorphic pebbles abundant.....	0 to 200

Spiti Valley, in the western Himalaya, is a classic locality for study of the Carboniferous, Permian, Triassic, and Jurassic systems, which have great development there. The Permian consists of a basal conglomerate and quartzite overlain by calcareous, fossiliferous sandstone which in turn is overlain by dark shales rich in brachiopods, including species of *Productus*.

WIDESPREAD EVIDENCE OF PERMO-CARBONIFEROUS
GLACIATION

The Gondwana rocks are of interest in revealing marked evidence of climatic changes. The basal beds, probably of Permo-Carboniferous age, include "boulder clays," bearing the usual marks of glacier-transported materials, such as rocks with smoothly planed and faceted surfaces and striations, while the substrata show planation, parallel striations, and locally reveal typical *roche moutonées*. Such deposits have been recognized not only at many localities in the Peninsula, but also in the Salt Range. The Aravalli Range is believed to have been the principal gathering ground for the snow fields from which the glaciers radiated in all directions. The "boulder clay" beds are made up of heterogeneous material, much of which obviously has been transported from distant sources. Many of the boulders in the Salt Range deposits are striated, polished blocks of rhyolite, of appearance identical with an occurrence of pre-Cambrian age in Rajputana, over 500 miles to the southeast. That other parts of Gondwanaland also had a glacial epoch at this time is established by the discovery of unmistakable evidence in Australia and also in South Africa, where glacial deposits lie at the base of the coal-bearing Karoo system, the rocks of which resemble the Gondwana.

THE GONDWANA COAL FIELDS

Evidently the cold climate at the beginning of the Permian was followed by a much warmer climate favoring an abundant vegetation, for India's most valuable coal beds were formed at this time. The occurrences are widely distributed over the Peninsula in numerous independent basins. These basins are scattered over Bengal, Bihar, Orissa, Central India, Central Provinces, and Hyderabad, but the greater part of the coal mined is from Bengal, Bihar, and Orissa, which have extensive deposits and are best situated geographically for exploitation, being convenient to the large markets. During recent years the average annual output of coal from Gondwana sources has been around 19,000,000 tons, more than 90 per cent of which has come from Bihar and Orissa. The production from Tertiary fields is insignificant, being less than 500,000 tons annually, derived chiefly from Assam, the Salt Range, and Baluchistan.

The coals are of the bituminous type, the best being comparable to the Carboniferous coals of the Appalachian region, though somewhat poorer quality as marketed, being high in ash. Analyses of the better coals commonly show 9 to 14 per cent ash, and in some of the coal marketed the amount apparently runs as high as 20 per cent. Sulphur is generally low, commonly less than 1 per cent, and much of the coal can be coked, giving a product suitable for metallurgical purposes.

Most of the fields have many coal beds, some of which are remarkably thick; a bed in the Bokaro field of Bihar being reported as 120 feet in thickness, and beds 25 to 50 feet, common elsewhere. The thick beds generally contain numerous shaly layers too high in ash to be utilized. In most fields the beds mined usually range from 5 to 15 feet in thickness.

Most of the coal mined in India is consumed locally, and even during the war, when the supply of Welsh coal for use in the East failed, the Indian product did not win a place of prominence, the demand for bunker fuel being supplied chiefly by Japan, Australia, and South Africa. Probably the prejudice against Indian coals has been justified, since the product, as marketed in earlier years, must have been of inferior quality. Later, however, with the introduction of better methods of mining, intelligent selection of beds, and careful rejection of impurities, the quality has been greatly improved.

PROBABLE ABSENCE OF PETROLEUM

It is doubtful whether the Permian strata contain commercial accumulations of oil anywhere in India. The Gondwana basins are too restricted and in other ways unfavorable for preservation, even though conditions favoring formation had existed. Seepages and other direct indications of oil are, so far as known, lacking. The Gondwana coals are, however, generally of bituminous grade, except locally, where altered by intrusives, the ratio of volatile constituents to fixed carbon being comparable to that of the Carboniferous coals within the oil fields of western Pennsylvania and the mid-Continent region. In most of the extra-peninsular areas of Permian, pronounced structural deformation and mild regional metamorphism have been so general that it is improbable that valuable accumulations of petroleum are preserved.

THE BATSON OIL FIELD, HARDIN COUNTY, TEXAS

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ABSTRACT

The Batson oil field, which has produced 32,000,000 barrels of oil, is underlaid by an elliptical anhydrite-capped salt plug, 2 miles long and 1½ miles wide. The formations encountered are Pleistocene to Oligocene. Most of the production comes from the cap rock and Oligocene formations. The field is now (1925) producing 1,400 barrels per day from 400 wells. Production curves, contours on the cap rock and cross-sections are shown.

INTRODUCTION

Location.—The Batson oil field is located on the west fork of Pine Bayou, 1 mile north of the village of Batson in Hardin County, Texas, 6 miles west of Saratoga and 9 miles north of Hull. The nearest railroads are the Gulf Coast & Santa Fe through Saratoga and the Beaumont, Sour Lake & Western through Hull.

History.—After the production from the two Gulf Coast oil fields, Spindletop and Sour Lake, began to decline, the Paraffine Oil Company was organized by S. W. Pipkin, W. L. Douglas, and other business men of Beaumont who had, up to this time, no experience in the oil business. Previous to this, W. L. Douglas, who had observed gas in some water holes and shallow wells in this vicinity, sent some samples of spongy earth to a Beaumont chemist who reported that they contained paraffin. Although the idea that this material was an indication of oil was ridiculed for some time, paraffin earth, which was first collected at Batson, is now considered one of the best indications of oil in the Gulf Coast.

On October 31, 1903, nine days after their drilling rig was unloaded at Liberty, the Paraffine Oil Company completed a well at a depth of 790 feet producing 600 barrels of oil per day. Six weeks later their No. 2 was flowing over 4,000 barrels per day from a depth of 1,000 feet. Their No. 3 well went into cap rock and the initial production was 10,000 barrels per day.

Since the location of the discovery well proved to be near the center of the dome, a rapid drilling campaign took place and the

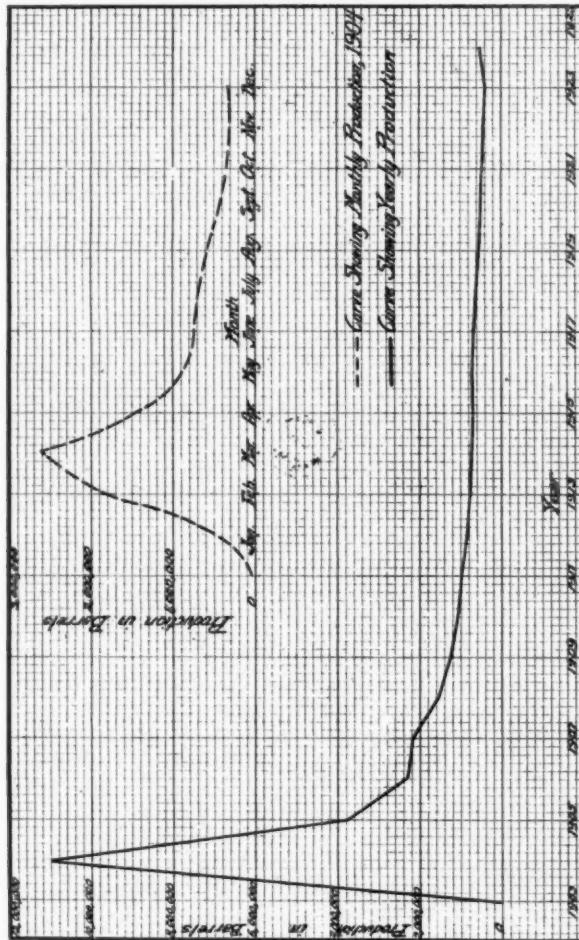
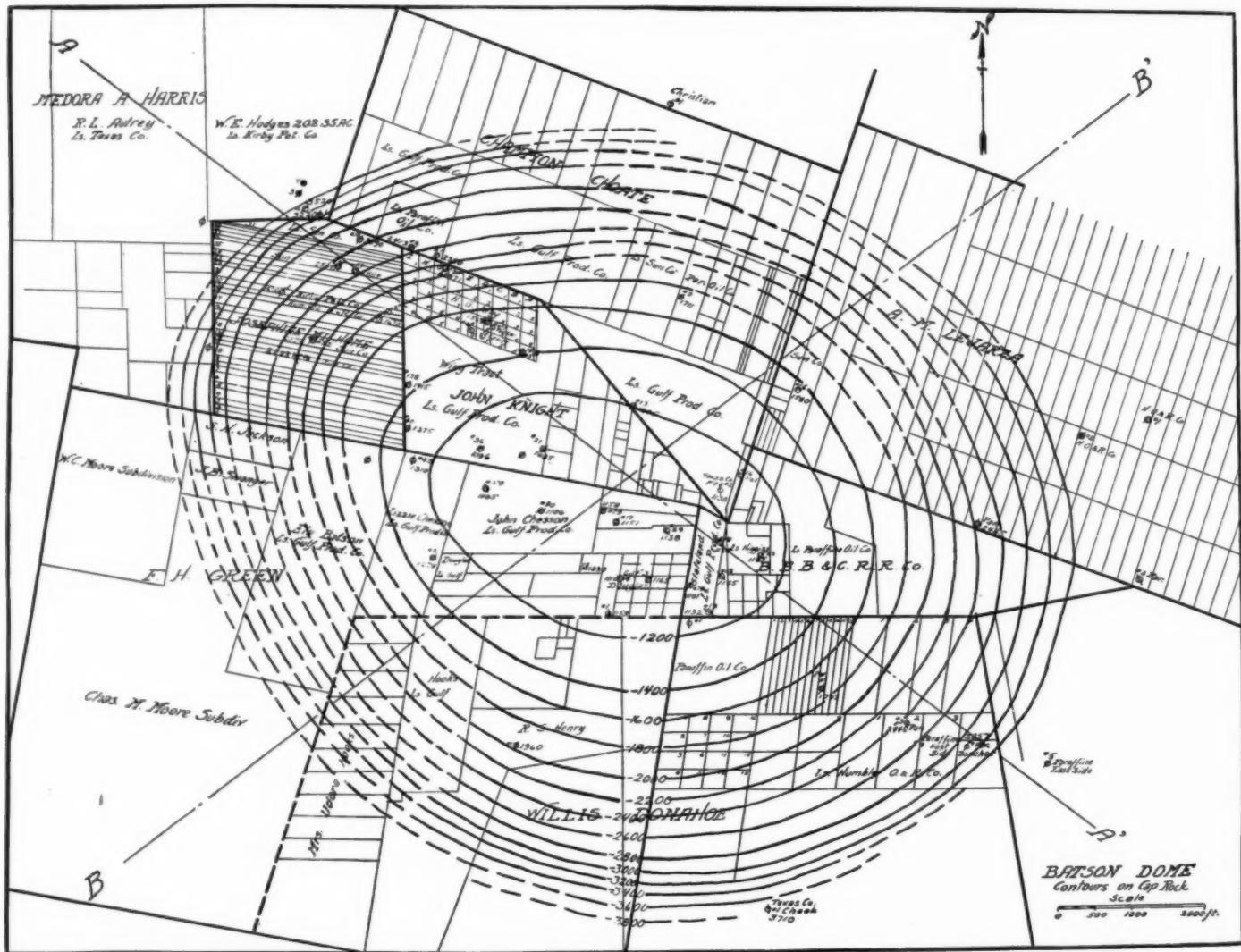


FIG. 1

peak production, 150,000 barrels per day, was reached March 4, 1904, after which, due to salt water, the decline was very rapid (Fig. 1).



PHYSIOGRAPHY

The surface elevation of the Batson field is 60 feet above sea-level and not more than 10 feet above the surrounding country. Because of dense forest this small relief could not be observed when the field was discovered.

SALT CORE

The Batson field is underlaid by an anhydrite-capped salt core which is elliptical in horizontal plane with the major axis running in a general northwest-southeast direction. The top of the dome is greatly undulating and covers an area of 400 acres. The highest point on the cap rock is 1,081 feet below the surface. At the 4,000-foot contour the dome is 2 miles long and 1½ miles wide (Plate 28).

Since most of the wells drilled at Batson lost returns in or near the cap rock, only one well was carried into the salt. The Gulf Production Company Douglas No. 3 hit cap rock at a depth of 1,162 feet and salt from 2,050 feet to 2,170 feet. The Gulf Production Company Wing No. 138 hit cap rock at 1,412 feet and had hard rock with thin layers of gypsum to 1,812 feet. Both of these wells were abandoned.

The Kirby Petroleum Company obtained cores of white granular massive anhydrite from three wells on the west side of the dome. None of the logs obtainable showed any sulphur.

Drillers who had completed wells on the west side of the field stated that there were a false cap and a break of soft material above the real cap rock. Cores from the Kirby No. 1 Milhome showed this false cap to be 6 feet of highly cemented sandstone and the soft material to be 4 feet of volcanic ash.

SEDIMENTS

The surface material at Batson is a mixture of sand and clay, probably of Pleistocene age. Wells off the dome show 1,000 feet of Lafayette and under this from 1,200 to 1,800 feet of Fleming, followed by 200 feet to 800 feet of Oligocene. On top of the dome there is a thinning and compression of beds (Fig. 2).

A core from the Cavit-King No. 1 shows Oligocene at 1,180 feet. The Cavit-King No. 2 shows volcanic glass suggestive of the Oligocene at 1,060 feet. The lithology of a sample taken from one of the

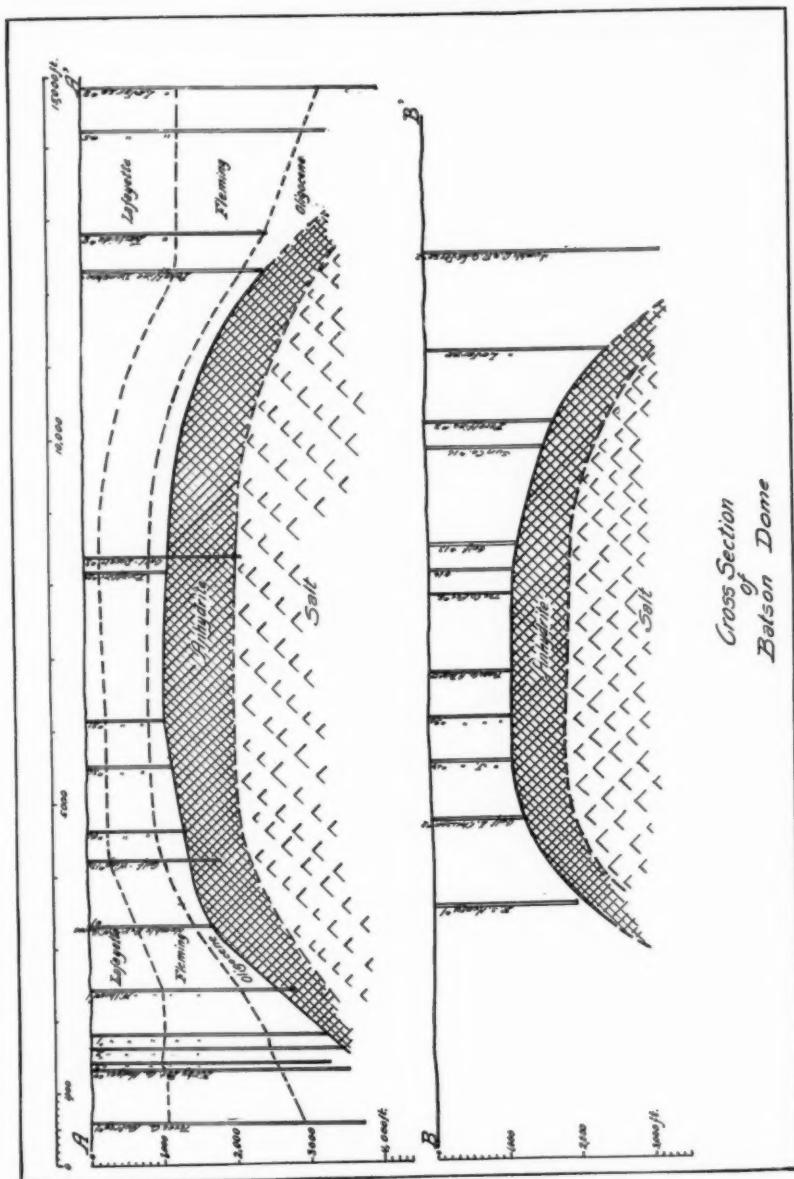


FIG. 2

Paraffine wells on the top of the domes compares with that frequently found in the upper non-fossiliferous Oligocene (cores examined by A. C. Ellisor.) The Oligocene in the Texas-Autrey No. 1 on the west side of the dome is approximately 400 feet higher than the same formation in the Paraffine-Humble Lejarza No. 3 on the east side.

The Eocene has never been observed in any of the Batson wells, but the following cores containing a foraminiferal fauna indicative of the Oligocene have been found in wells off the dome:

Texas Company-Autrey No. 1, samples examined by H. T. Kniker,

Depth 3,063 feet
Balanus sp.
Discorbis bertheloti
Globigerina sp.
Depth 3,156 feet
Amphistegina lessonii
Pulvinulina texana
Depth 3,704 feet
Haplophragmium sp.
Polystomella striatopunctata

Paraffine-Humble Lejarza No. 3, samples examined by A. C. Ellisor,

Depth 3,747 feet
Heterostegina antillea
Polystomella texana
Pulvinulina texana
Cristellaria sp.

It is interesting to note that in the Texas-Autrey No. 1, 1,000 feet off the west side of the dome, a sand core from a depth of 3,063 feet had a dip of 47 degrees, a sandstone core from 3,170 feet showed a dip of 38 degrees, and a shale core from 3,729 feet had a dip of 44 degrees.

PRODUCTION

The 1,150 wells drilled in the Batson field have produced over 32,000,000 barrels of oil from 560 acres of land ranking eighth among the Gulf Coast fields in total production, and it is now (1925) producing 1,400 barrels per day ranking tenth in present daily production. Part of this oil comes from the cap rock, and part of it is produced from sands which are encountered at various depths from 189 feet to 3,500 feet. One company, now producing oil in this field, is pumping 44 wells averaging 10 barrels per day per well and their lifting charge is 40 cents per barrel.

Batson has produced a great variety of oils. The Sun Company had a shallow well yielding 14.6° Bé. oil. The Kirby Petroleum Company brought in a 5,000-barrel well on the Hodges lease with 40° Bé. gravity oil at 3,230 feet, but it produced only a few days.

Since this rapid decline is the history of nearly all light oil wells in the Gulf Coast, a method was desired whereby the gravity of the oil could be determined by analysis of the oil from the core, thus eliminating the testing of sands which contained light oil. Dr. L. Porter, chemist for The Texas Company, had previously suggested the miscibility of water and alcohol. Many experiments in the Kirby Petroleum Company laboratory resulted in the following very successful method: The oil is leached from a sand core with ether and a drop of the oil obtained is added to a quantity of alcohol in a hydrometer jar. The oil, being heavier than alcohol, sinks. By the slow addition of water an alcohol-water solution can be obtained which has the same gravity as the oil, thus causing the drop of oil to migrate through the solution. The gravity of the solution is then obtained by the use of a hydrometer. In two offset wells, the application of this method enabled the operators to set screen in sands which produced 24° Bé. and 20° Bé. gravity oil.

Many wells on the west side of the dome encountered an enormous gas pressure at depths of 1,800 feet, 2,800 feet, and 3,200 feet, but the pressure never held up for more than a few days. The high pressure was probably due to the fact that the formations there are sealed by compression and faulting. For the same reason none of the oil wells drilled on the Hodges lease have held up although all four of these wells came in with an initial production of more than 1,000 barrels per day per well.

ACKNOWLEDGMENTS

Samples of cap rock were furnished by W. G. Christian, of Houston, and cores of the shallow sands were furnished by W. H. Cavit, of Batson. Logs of wells were secured from the Paraffine Oil Company, Humble Oil & Refining Company, Gulf Production Company, and The Texas Company. The paleontological analyses of cores by A. C. Ellisor were especially helpful.

THE BAYOU BOUILLOUN SALT DOME, ST. MARTIN PARISH, LOUISIANA

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ABSTRACT

The Bayou Bouillon salt dome is located in the swamps northeast of Martinville, Louisiana. Cap rock appears to occur at depths of 1,500 to 2,000 feet. The salt has a rather gentle slope on the east and north, but the west and south sides of the dome are unexplored. Small quantities of heavy black oil have been found in shallow sands.

LOCATION

The Bayou Bouillon salt dome is in St. Martin Parish, Louisiana, in Township 9 South, Ranges 8 and 9 East, 15 miles northeast of St. Martinville. Situated in the midst of the Atchafalaya swamps, Bayou Bouillon can only be reached by boat. The most convenient point of access is Atchafalaya, a station on the Baton Rouge branch of the Southern Pacific Railway. The intricate system of bayous, lakes, and rivers in the swamps makes it possible to barge machinery and supplies into the district very cheaply.

The drilling crews usually live on houseboats, for the only dry land is that on the natural levees along the rivers, and this is covered with water for several months of the year. Fishing, lumbering, and gathering moss are the main occupations of the inhabitants, who live in small houseboats or in houses on the high ridges along the waterways of the swamp.

HISTORY

Bayou Bouillon means "bubbling" or "boiling" bayou. As early as 1833 this boiling was noticed, and old maps show the location of the bayou as we know it today. The Spindletop discovery in January, 1901, called attention to the oil possibilities of the Gulf Coast region, and two swampers, George Knight and E. A. Davis of St. Martinville, who had spent many years taking timber out of the swamps, went to Bayou Bouillon and found that the bubbles

¹ Consulting Geologist.

would burn. With Robert Martin and others they immediately purchased several thousand acres of land in the vicinity.

In the year 1902 four wells were started at Bayou Bouillon. O. W. Heywood, of Heywood Brothers of Spindletop and Jennings,

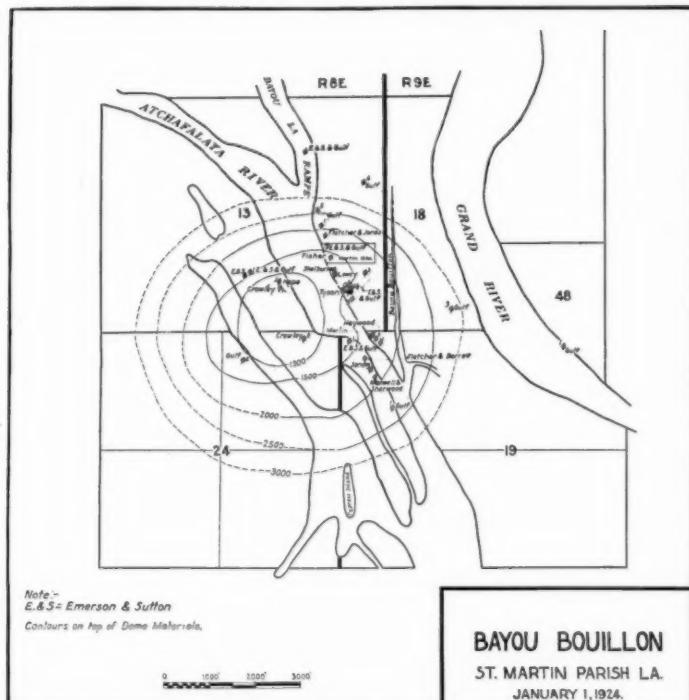


FIG. I

F. F. Maxwell and W. D. Sherwood, Charles A. Lowry, and Shelbourne and Kelso were the operators. Heywood lost his first hole at 365 feet and then drilled a second test to a depth of 1,089 feet. All of these tests had showings of oil and gas, and it is said that some oil was bailed from the Heywood No. 2. By the summer of 1903 these tests had been abandoned. During the succeeding years a few holes were put down, the most important being the Crowley Oil and Mineral Company No. 2, which struck salt at about 1,650 feet.

In 1916 Sloan Emerson and Jim Sutton, who had been successful at Vinton and Edgerley, obtained leases and interested the Gulf Refining Company of Louisiana. Nine tests were drilled. One shallow well made about 25 barrels of oil per day and furnished fuel for operations for a period of two or three months. The Gulf Refining Company on its own account drilled No. 1 Prohaska on the east side of the Grand River in Iberville Parish.

In 1919, after the Gulf Refining Company had withdrawn, Emerson and Sutton drilled a 449-foot well which made about 10 barrels of oil per day.

In 1921 the Gulf Refining Company started drilling again and put down six tests. In 1923 the Gulf surrendered its leases.

In February, 1924, most of the land around the dome was purchased in fee by the Rycade Oil Corporation.

PREVIOUS REPORTS

Fenneman¹ and Harris² have published brief descriptions of Bayou Bouillon. Both of these authors state that 300 feet of limestone was reported in the Maxwell and Sherwood well between the depths of 850 and 1,150 feet, while the log of the well, as published, shows only 20 feet of "lime" from 830 to 850. However, this may be a typographical error, for Robert Martin, of St. Martinville, has a log in his office which shows "lime" from 850 to 1,150 feet. That this "lime" is cap rock is questionable, for sand is reported beneath it and subsequent drilling seems to indicate that the cap rock is between 1,500 and 2,000 feet in depth where this well was put down. In various papers Lee Hager, William Kennedy, Sidney Powers, and Alexander Deussen have mentioned Bayou Bouillon as one of the Gulf Coast salt domes.

PHYSIOGRAPHY

As has been noted, Bayou Bouillon is in the Atchafalaya swamps. No topographic mound is present. "Ridges" run through the swamps and along the banks of the rivers but these are probably

¹ N. M. Fenneman, "Oil Fields of the Texas-Louisiana Gulf Coastal Plain," *Bull. U. S. Geol. Survey No. 282* (1906), p. 112.

² G. D. Harris, "Oil and Gas in Louisiana, etc.," *Bull. U. S. Geol. Survey No. 429* (1910), pp. 13 and 41.

BAYOU BOUILLOON, ST. MARTIN PARISH, LOUISIANA, WELL DATA

Operator	Lease	Well Number	Date Completed	Total Depth (Feet)	Remarks
Crowley Oil & Mineral Co.	Sec. 13	1	4/12/12	1,264	
Crowley Oil & Mineral Co.	Sec. 24	2	7/31/14	1,866	Salt at 1,650?
Emerson & Sutton.	Hope Oil Co. (Sec. 13, west of the river)	1	2/18/19	449	Made 10 bbls. of oil from sand at 437 to 449
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 19)	1	5/26/16	1,360	Cavity at 1,360; lost log
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 13, on east side of river)	2	9/10/16	1,740	1,674-1,740, black and white rock and lots of gypsum
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 13, on east side of river)	2½	10/25/16	435	Produced about 25 bbls. of oil per day from sand at 412-435
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 13, on east side of river)	3	1/10/17	1,620	1,550-1,620, black and white rock and lots of gypsum
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 13, on east side of river)	4	1/17/17	630	Salt water
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Hope Oil Co. (Sec. 13, on east side of river)	5	3/15/17	470	Salt water
Emerson & Sutton and Gulf Refining Co. of Louisiana.	Crowley-Martin 10 acres (Sec. 13)	1	6/10/17	1,847	1,700-1,786, hard sand and lignite (1,700-1,710, tested; blowout; 1,780-1,812, gumbo and gypsum; 1,812-20, gypsum and broken rock; 1,820-28, black shale, hard sand, oil; 1,828-47, hard, porous, black rock

Emerson & Sutton and Gulf Refining Co. of Louisiana.....	State land (Bayou La Rampe)	1	1/11/18	3,000	No dome materials
Emerson & Sutton and Gulf Refining Co. of Louisiana.....	Atchafalaya Oil & Mineral Co. (Sec. 13, west of river)	1	3/31/18	1,615	1,500-1,510, gypsum and boulders; 1,510-1,615, black and white rock with gypsum; located on Starvation Ridge, known as well No. 6
Fisher.....	Martin 10 acres (Sec. 13)	1	330	
Fletcher & Jones.....	Sec. 13	1	1903	Shallow test
Fletcher & Barrett.....	Sec. 19	1	1904	Shallow test
Gulf Refining Co. of Louisiana.....	Prohaska (Sec. 48)	1	7/29/17	2,940	No dome materials
Gulf Refining Co. of Louisiana.....	Hope Oil Co. (Sec. 13)	1	5/17/21	2,063	Cap rock 2,055-63; tested for oil at 2,031
Gulf Refining Co. of Louisiana.....	Hope Oil Co. (Sec. 13)	2	8/25/21	2,690	Tested for oil at 2,490-2,521; blue and black lime, 2,587-2,622; salt at 2,622-90
Gulf Refining Co. of Louisiana.....	Hope Oil Co. (Sec. 18)	3	1/24/23	3,000	2,401-74, hard sand and lime; 2,474-2,800, hard white sand; streaks of gypsum 2,800-2,852, sand and salt; 2,852-3,000, salt
Gulf Refining Co. of Louisiana.....	Hope Oil Co. (Sec. 13)	4	7/10/23	3,560	Tested at 2,360 and 3,165
Gulf Refining Co. of Louisiana.....	Atchafalaya Oil & Mineral Co. (Sec. 19)	1	2/9/22	1,895	1,679-84, shale and lime; 1,684-1,895, sand and lime
Gulf Refining Co. of Louisiana.....	Atchafalaya Oil & Mineral Co. (Sec. 24)	2	10/15/23	1,377	1,324-26, gypsum rock; 1,326-32, black and white rock; lost returns; 1,332-77, sand rock and gypsum; lost returns
Heywood Brothers.....	Sec. 19	1	1902	365	See U. S. Geol. Survey Bull. 429, p. 41

BAYOU BOUILLON, ST. MARTIN PARISH, LOUISIANA, WELL DATA—Continued

Operator	Lease	Well Number	Date Completed	Total Depth (feet)	Remarks
Heywood Brothers	Sec. 19	2	1903	1,089	See <i>U. S. Geol. Survey Bull.</i> 429, p. 41. Robert Martin attempted to deepen this hole but was unsuccessful, so he moved his rig a short distance and drilled the "Grant well."
Hope Oil Co	Sec. 13	1	1908?	1,166	
C. A. Lowry	Sec. 13	1	1903	1,400	
Martin <i>et al.</i>	Sec. 19	1	1908	1,800	"Black hot salt water." Located near Heywood wells, known as Grant well
Maxwell & Sherwood	Sec. 19	1	1903	1,555 ² 1,562 ² 1,582 ² 1,795 ²	See <i>U. S. Geol. Survey Bull.</i> 282, p. 113, and <i>Bull.</i> 429, p. 41, for log
Sandoz	Sec. 19	1	1908	1,600	Known as Eberhardt well
Shelbourne	Sec. 13	1	1902	810	See <i>U. S. Geol. Survey Bull.</i> 429, p. 41, and <i>Bull.</i> 282, p. 113, for log
Tyson	Sec. 13	1	11/5/15	290	

the result of the deposition of silt from the flood waters of the Mississippi which find their way into the Atchafalaya and thence to the Gulf of Mexico.

GEOLOGY

Along the banks and in the bed of the Bayou Bouillon there are gas escapes and beds of "paraffin dirt." Fenneman¹ evidently refers to "paraffin dirt" when he mentions the "occasional occurrences of an oily or asphaltic matter in the soil."

The extent and shape of the cap rock and salt are not known on the west and south sides of the dome. The information concerning many of the wells drilled is meager or entirely wanting.

The dome is probably cone shaped. On the east and north sides, as far as revealed, the flanks of the salt have, for a salt dome, a gentle slope. The thickness of the cap rock on top of the salt is not known, but it is probably 250 or 300 feet.

There is no log available of the Crowley No. 2 well, the only test which went through the cap rock on top of the dome and into the salt. Gulf Refining Company of Louisiana No. 2 Atchafalaya Land and Mineral Company found porous cap rock at 1,324 feet, the shallowest of which a record can be found. Gulf Refining Company No. 2 Hope Oil Company reports 35 feet of "blue and black lime" from 2,587 to 2,622 feet, and salt from 2,622 to the bottom of the hole at 2,690. Gulf Refining Company No. 3 Hope Oil Company reports salt at 2,852, but no cap rock overlying the salt.

OIL AND GAS

Only small amounts of heavy black oil have been produced at Bayou Bouillon from shallow wells. Nearly all the wells drilled report sands showing oil.

The possibilities of this dome as a producer of oil are by no means exhausted. The west and south flanks of the salt core have never been explored.

¹*Op. cit.*, p. 112.

SECTION 28 SALT DOME, ST. MARTIN PARISH LOUISIANA

DAVID DONOGHUE
Houston, Texas

ABSTRACT

Gas and "paraffin dirt" prompted drilling of a test well northeast of St. Martinville, Louisiana. A showing of oil was found at a depth of 900 feet, and salt from 1,250 to 2,500 feet. There was no cap rock.

The Section 28 salt dome is in St. Martin Parish, Louisiana, 8 miles northeast of St. Martinville, in Township 9 South, Range 7 East, and in the western part of the Atchafalaya swamps. This locality has been called Catahoula Lake, Parks, and the Hager-Martin dome. A more appropriate name would be Bayou Martin, but as those who are interested in the locality commonly refer to it as Section 28, this name has been adopted for this paper.

In the year 1916 Lee Hager and W. C. Moore published a pamphlet entitled *Indications of Oil in the Gulf Coast Country*, which had wide circulation and aroused much interest in the search for new domes. As a result, Derneville Barras, of St. Martinville, found gas, and later Lee Hager found "paraffin dirt," near the southwest corner of Section 28, at the spot where the Hager well was later drilled. Robert Martin and his associates purchased lands around the prospect and made arrangements with Lee Hager and E. F. Simms to drill a well. The location was accessible only during periods of high water, so the derrick was built on piles 8 or 10 feet above the swamp level, and drilling started in May, 1917, and was completed in June, 1918.

A showing of oil was found at a depth of about 900 feet. No cap rock was encountered, but salt was found at 1,250 feet and continued to the bottom of the hole at 2,500 feet.

Deussen¹ gives the following information concerning material from this test:

¹ Alexander Deussen, *Bull. Amer. Assoc. Pet. Geol.*, Vol. II (1918), p. 22.

A somewhat unusual find in this well was a sample of pinkish siliceous rock at a depth of 1,220 feet. Analysis showed a trace of sulphate of lime and about 35 per cent of carbonate of lime. It resembled volcanic ash, but Dr. Udden, to whom a sample was submitted, reported no ash present. The rock consists mostly of fine quartz grains with some zircon fragments. Somewhat similar

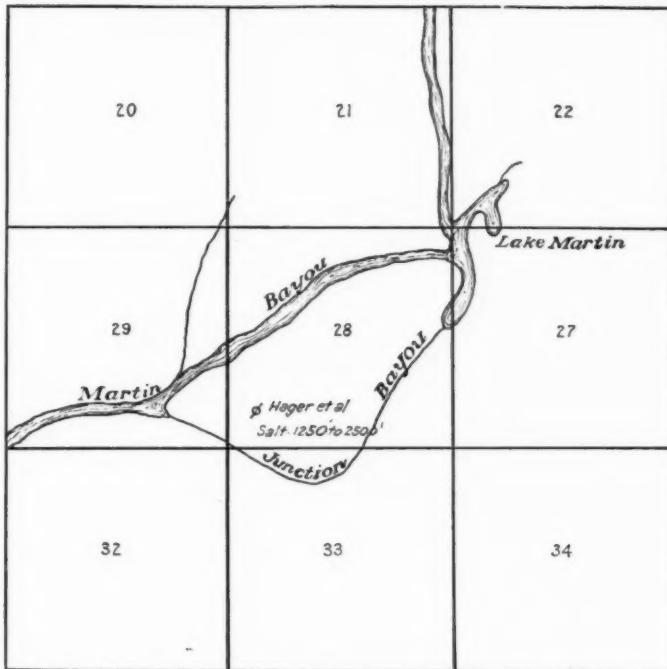


FIG. 1.—Section 28 Salt Dome, T. 9 S. R. 7 E., St. Martin Parish, La.

deposits are encountered in the outcrop of the Fayette sandstones of Texas and west Louisiana some 100 miles to the northwest, and they also occur in the Catahoula formation which outcrops about 90 miles to the north. If a part of this formation, the normal position of these beds would be considerably deeper than found in this well, so that the evidence of uplift is unmistakable.

Since the completion of the Hager well the levee system has been extended, drainage canals are now being excavated, and preparations are being made for the building of a road to the dome from the

state highway between Isle Labbe and Catahoula Lake. "Paraffin dirt" and gas have recently been found at other points near the Hager well. It is possible that these indications will be found all around the edge of the salt mass.

LOG OF WELL¹

Formation	Depth (Feet)
Blue gumbo.....	83
Blue shale.....	103
Water sand.....	124
Sand shale.....	145
Blue shale.....	165
Shale boulders.....	186
Sand.....	208
Shale.....	228
Gumbo.....	239
Sand gravel.....	274
Cemented sand gravel.....	301
Gumbo.....	313
Hard gravel.....	324
Lime rock.....	328
Gumbo.....	335
Shale.....	340
Lime shell.....	341
Gumbo.....	366
Hard blue shale.....	396
Gumbo boulders.....	403
Gumbo boulders.....	406
Sand blue shale.....	429
Sand gravel.....	451
Sand gravel.....	492
Rock pyrites lime.....	497
Sand.....	508
Gumbo.....	517
Gravel.....	520
Gumbo.....	570
Lime rock.....	585
Shale boulders.....	628
Rock cemented sand set 10".....	640
Cemented sand, very hard in streaks.....	710

¹ Drilled by Lee Hager, E. F. Simms, *et al.*, on Section 28 Salt Dome, St. Martin Parish, Louisiana. Drilling started May, 1917; drilling completed June 1, 1918.

SECTION 28 SALT DOME

1293

Formation	Depth (Feet)
Cemented sand and gravel	
Barrels of nearly pure lime	
Thin streak of black shale	
Running Hughes bit last 5 feet	
No report	804
Gyp rock with breaks of shale	951
Crystallized sand; contained water	1,030
Crystallized sand; breaks of gyp	1,085
Crystallized sand, gyp, hard rock	1,136
Packed sand and boulders	1,155
Rock	1,167
Gypsum	1,171
Packed sand	1,186
Rock	1,190
Packed sand	1,193
Rock	1,205
Packed sand	1,209
Rock	1,214
Hard sand	1,227
Dark grey sand	1,235
Pink sand, very salty	1,250
Broken salt and sand	1,277
Salt rock	2,500

GEOLOGICAL NOTES

FURTHER NOTE ON BARITE PISOLITES FROM THE BATSON AND SARATOGA OIL FIELDS

The barite oölites from the Saratoga oil field have been described several times, most lately by Suman,¹ who quotes an earlier description by E. S. Moore. E. G. Woodruff is quoted by Moore as stating that some of the pisolites were of much larger size than the mesh of the screen in the well from which they were produced and, therefore, must undoubtedly have formed in the wells after the screen was set. In looking over a sample of the pisolites which were said to have been obtained in cleaning out a well in the Batson oil field, the writers noticed a number of flat disk-like pisolites among the usual spheroidal ones. The flat pisolites were about 5 to 8 mm. in diameter, and some 2 to 3 mm. thick. When broken, they were seen to consist of a thin, flat dark plate surrounded by the normal radiating tubes and cortical layers of barite, characteristic of the spheroidal pisolites. The platy core was about the size and shape and thickness of many pieces of pipe scale, and, as it was strongly magnetic, the writers believe it to be a piece of pipe scale. This presence of pipe scale as the core of pisolites corroborates Woodruff's belief that some of the pisolites are formed in the well after its completion.

In discussion of the origin of the pisolites Moore concludes that "It would be practically impossible for bacteria or other low types of life, which are believed to play an important part in the origin of oölites, to exist in a liquid with such strong antiseptic qualities as those of warm petroleum containing considerable sulphuric acid.

The work of Baldwin,² however, shows that although petroleum greatly retards the activity of most types of bacteria, it greatly increases the activity of a few types. The more detailed work of Soehngen³ and others shows that certain bacteria live on and break down the paraffin hydrocarbons. The concentration of the sulphuric acid, if it is present,

¹ John Suman, "The Saratoga Oil Field, Texas," *Bull. A. A. P. G.* (1925), Vol. 9, No. 2, p. 275.

² I. L. Baldwin, thesis for MS., Purdue University.

³ N. L. Soehngen, *Centralblatt f. Bakteriologie* (1913), Abt. 2, Bd. 37, S. 595-609.

must be very low. It would, therefore, seem unsafe to conclude that bacterial activity cannot have some part in the formation of these pisolithes.

DONALD C. BARTON AND S. L. MASON

RYCADE OIL CORPORATION
HOUSTON, TEXAS

AN ALIBI FOR GEOLOGISTS

Did you ever choose the location for a well which failed to strike oil? Of course most geologists have never done such a thing, but for the benefit of the few who have permitted themselves to be caught in that situation without a single "but" or "however" to fall back upon, I take pleasure in citing the following:

Well No. 21 on the S.E. $\frac{1}{4}$ of Section 34-40-79, Salt Creek Field, Wyoming, was commenced on November 3, 1924. It was just an inside location, drilled in the normal course of development, and no one's reputation was at stake. At 1,313 feet it reached the top of the First Wall Creek sand; at 1,375 found a small show of oil; and at 1,422 looked good for about 10 barrels per day. When casing was run it stopped at 1,361, showing a crook in the hole at that point. After attempting unsuccessfully to straighten the hole in the sand the well was filled with rock back to 50 feet from the surface and a new hole started. The new hole reached the top of the sand at 1,310, showed oil at 1,340, and began to flow at 1,400. It was called a completion on May 5, and on May 8 pumped 320 barrels. An almost dry hole and a 320-barrel well under the same derrick floor!

Moral: Don't let the driller bluff you—your location was all right but they couldn't drill straight down to the point you wanted.

P.S.—The writer believes this is one of the comparatively rare cases where "a fault" has something to do with the results. The dry hole "slid off" into an inclined fault plane with more or less indurated walls.

E. L. ESTABROOK

OIL FIELDS OF CHINA, AN ACKNOWLEDGMENT AND OUTLINE OF RECENT ACTIVITIES¹

¹ Following publication of a paper entitled "Oil Fields of China" by T. O. Chu of the Geological Survey of China in Volume 8, pages 160-77, of this *Bulletin*, Mr. James H. Gardner, under whose sponsorship the contribution was submitted, wrote to the Editor advising that his attention had been called to the inclusion in Mr. Chu's writing of many geological data gathered by American workers to whom no acknowledgment was made. On referring the matter to the author, the following statement accompanied

by a letter from the Director of the Geological Survey of China, Mr. W. H. Wong, expressing regret for the omissions in Mr. Chu's paper was received. The additional discussion of recent activities in the Chinese fields is of interest and value.

INTRODUCTION

At the last International Petroleum Congress, held at Tulsa, Oklahoma, October, 1923, where I was present as a representative of the Geological Survey of China, I was invited to give a summary of what we know today of the oil fields of China. This summary was published in the *Bulletin of the American Association of Petroleum Geologists*, Vol. VIII, No. 2. In this brief and general review, no acknowledgment was made of the various sources of our information. This omission was unfortunate because the recent work on the extensive oil fields of which I have outlined the geological characters is mostly unpublished and ought to be credited to its proper authors. This is so much the more regrettable as it may be interpreted by those who have done the prospecting in the field as a lack of appreciation of their work on my part. I feel, therefore, grateful to the *Bulletin of the American Association of Petroleum Geologists* for the space allowed to this supplementary note.

SHENSI

Extensive prospecting work was done in Shensi during 1914-15. The work was carried on as a Chinese and American joint enterprise by the Standard Oil Company of New York and the National Oil Administration of China. The geological work was done by a number of American specialists among whom F. G. Clapp and M. L. Fuller may be specially mentioned. Detailed maps, both topographical and geological, of several special areas were surveyed and a general geological map of north Shensi on the scale of 1:1,000,000 was compiled. All the reports are now in the possession of the Geological Survey of China. The geological material is, however, scattered through a large number of reports and letters, and it would be difficult to grasp the essential points except for the good summary written by E. L. Estabrook. The general section, according to the American geologists, was given in Figure 2 of my first paper. The sedimentary formations are as follows, according to these authors:

Red and green sandstone	Mesozoic
Red cross-bedded sandstone with marly limestone at base	Permian
Shensi series (coal and oil bearing)	
Fenho series (red sandstone)	Carboniferous
Shansi series (coal bearing)	
Sinian limestone: Younger Algonkian and Cambro-Ordovician	
Granite and Metamorphics: Archean and Older Algonkian	

C. C. Wang, my colleague of the Geological Survey, made in the autumn of 1922 and the spring of 1923 two east-west cross-sections in north Shensi, one in the Taliho Valley and the other along the Great Wall. He surveyed also the southeastern part of the Ordos which is geologically a continuation with north-

ern Shensi. He found in the Shensi series a rich flora of Lower Jurassic (Liassic) age. Among the genera recognized are: *Baiera*, *Pterophyllum*, *Podozamites*, *Thyrsoperis*, *Czekanowskia*, *Asplenicun*. It is therefore established that the oil-bearing Shensi series formerly referred to the Carboniferous cannot be older than the Lower Jurassic.

It was C. C. Wang also who found the first fossils from the thin limestone at the base of the cross-bedded sandstone, overlying the Shensi series. These consist mainly of ganoid fishes which are preliminarily determined by Smith Woodward of the British Museum as belonging to *Pholidophoridae* known in the Upper Jurassic of Europe.

The stratigraphical sequence of northern Shensi, first established by the geologists of the Standard Oil Company, is therefore to be rearranged as follows:

Red and green shale: Cretaceous

Red cross-bedded sandstone with thin limestone at base: Upper Jurassic
Shensi series: Jurassic

Fenho series: Triassic, lower part probably Permian

Shansi series: Carboniferous.

SZECHUAN

We owe our knowledge of the geology of the Szechuan field to C. D. Louderback and a number of American co-workers who were in that province in 1916, in the service of the National Oil Administration, under the general directorship of Hsiung Hsi Ling. While several deep borings were made in Shensi, the prospecting work in Szechuan was limited to outcrop examination and collection of data from the salt wells. The geological map and section of Tzu-liu-ching given as Figures 3 and 4 and the well data in Table II of my first paper are to be accredited to Louderback whose reports are now in the archives of the Geological Survey. The section given as Figure 5 was also compiled from his reports. The geological age of the formations was almost completely left out in Louderback's reports though it is understood that a number of fossils were found. When the material is worked out, Louderback's researches will throw the most important light on the geology of the great Szechuan basin and its northern bordering regions. No later work has been done since 1916.

WESTERN KANSU

Oil occurs in Yu Men, Tunwang and the neighboring districts of western Kansu, along a belt, sometimes called oases of Kansu, between the Nan Shan and Pei Shan ranges. The geology of the region was examined in 1921 by my colleague of the Geological Survey, C. Y. Hsieh, who found there a red sandstone formation overlying the oil-bearing series which is very probably equivalent to the Shensi series in Shensi.

JEHOL

In the Jehol administrative district, there are several regions where oil shales are found. These regions first drew the attention of the American geolo-

gists when it was a question of opening Chinese oil fields by Sino-American joint enterprise. But it was soon found that the Jehol field consists of nothing but small oil shale deposits and therefore no serious study was done. The geology has been recently examined by C. Tung and myself. We found there the Jurassic formation well developed and in its upper part the fossil fishes *Licoptera* are the most abundant.

In concluding, I once more express my regret for not having duly acknowledged in my first paper the work done by other geologists from which I have drawn material. I had, however, no intention to let it appear as all my own. It is earnestly hoped that these important researches on the geology of China of which I have only tried to sum up the essential points, will be worked out properly and quickly published for the good of the scientific public, and I am sure that the Geological Survey of China will give its best support to this end.

T. O. CHU

GEOLOGICAL SURVEY OF CHINA

REVIEWS AND NEW PUBLICATIONS

Petroleum Engineering. By ROBERT WILLIAM PHELPS and FRANCIS WILBUR LAKE. Houston, Texas: Gulf Publishing Company.

The subject-matter is discussed under the following headings: Part I, "Petroleum Engineering and the Petroleum Engineer"; Part II, "General Geology," subdivided into "Dynamic Geology," "Structural Geology," and "Historical Geology"; Part III, "Petroleum Geology," which is discussed under the subjects of "Properties of Petroleum," "The Origin of Petroleum," "The Migration of Petroleum," and "The Accumulation of Petroleum"; Part IV, "Applied Petroleum Geology," subdivided into "Exploration," "Development," and "Production"; Part V, "Operating Technology"; Part VI, "Petroleum Economics," which is subdivided into "Appraisal" and "General Economic Status"; Part VII, Appendix, which includes schedules, tables, and charts.

The book covers a wide range of subjects in a brief way. It would seem desirable either to enlarge the book or narrow the field so that adequate details could be given in the limited space. In any event it could be made more valuable if references were given to tell where greater detail could be obtained on the various topics. This could be done either by footnotes or at the end of the discussion by listing references on each subject. In a book of this size it is naturally impossible to give all the practices of different producing districts, and in general the production and development practices referred to by the authors follow more closely those used in California rather than in the Mid-Continent or Gulf Coast.

The book contains examples of methods for keeping production records, drilling data, etc., as well as other information which is constantly used and needed by the production engineer in his study of the work in which he is engaged. I feel that the most valuable part of the book is the compilation of tables in the Appendix. This information is very much needed in the everyday work of the production engineer, and by having it in one book it is readily available and in much more convenient form than when scattered in several notebooks. I would recommend this book to the young petroleum engineer, and feel also that the more experienced petroleum engineer could well afford to have this book on his desk, primarily for the valuable compilation which has been made of tables and charts relating to the everyday work of the petroleum engineer.

A. W. AMBROSE

THE ASSOCIATION ROUND TABLE

MEMBERSHIP APPLICATIONS APPROVED FOR PUBLICATION

The Executive Committee has approved for publication the names of the following applicants for membership in the Association. This publication does not constitute an election, but places the names before the membership at large. In case any member has information bearing on the qualifications of these applicants, please send it promptly to Charles E. Decker, Norman, Oklahoma. (Names of sponsors are placed beneath the name of each applicant.)

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AT HOME AND ABROAD

CURRENT NEWS AND PERSONAL ITEMS OF THE PROFESSION

CHESTER W. WASHBURN, after spending the last year in Australia, is to spend another year in New Zealand as chief geologist of the Taranaki Oil Company. He sailed from San Francisco last December expecting to work later in Northern Africa, to join his family in France, and to complete a trip around the world westward. Now his wife and children are en route from France to New Zealand, and they, instead of him, will have the trip around the world eastward.

The Houston Geological Society held its annual business meeting October 2. Officers for the ensuing year were elected and the retiring officers submitted a report summarizing activities of the organization for the year ending October 2, 1925. The Society now has a membership of 116, who are actively engaged in various phases of the geological profession. Considerable progress has been accomplished under the leadership of JOHN R. SUMAN, president, A. C. ELLISOR, vice-president, DAVID DONOGHUE, and W. D. BLACKBURN, secretary-treasurer.

The newly elected officers were DILWORTH HAGER, president, ELIZABETH STILES, vice-president, and J. M. VETTER, secretary-treasurer.

N. H. DARTON of the U. S. Geological Survey has returned to Washington after an extended examination of the stratigraphy and structure of the Guadalupe Mountains and part of north-central Texas.

HARRY A. CAMPBELL, of Wichita Falls, Texas, has recently transferred from the Crown Central Petroleum Corporation of Houston, Texas, to be associated with T. G. Lomax, Jr., an independent operator of Wichita Falls.

At a geological luncheon of the Tampico geologists, held at Hotel Imperial, Tampico, November 4, DR. VON BÜLOW TRUMMER, of the Mexican Gulf, gave a very interesting talk on the uses of the Eotvos Torsion Balance in oil geology.

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